NSW DEPARTMENT OF
PRIMARY INDUSTRIES

Soil health: The foundation of sustainable agriculture
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Soil health in north coast agriculture: assessment and rehabilitation

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At the historic IFOAM (International Federation of Organic Agriculture Movement) meeting in Switzerland in 1977, which placed organic farming under the International spotlight, Lady Eve Balfour discussed works of numerous pioneers in the medical and agricultural field. She applauded their foresight.

> They looked at the living world from a new perspective- they also asked new questions. Instead of the contemporary obsession with disease and its causes, they set out to discover the causes of Health.

Since this pioneering review of health, agricultural research has begun to focus on the definition of soil health. Although many prominent research groups have defined soil health (Doran, Zeiss 2000 publish a good example), agriculture in the 21st century is still unable to capitalise on soil biota for economic or environmental sustainability.

In order to achieve sustainable agriculture, Sherwood and Uphoff (2000) argue that efforts are needed to better link multi-disciplinary research with practice and political actions. The achievement of sustainable agriculture was let down in the 20th century because research focused strongly on soil chemical and physical factors, with comparative neglect of biological factors. Concern about soil health is motivated by present and future interest in both agricultural productivity and profitability.

Many factors can have negative impacts upon soil health. These factors include loss of organic carbon (Islam, Weil 2000), compaction (Singleton, Addison 1999), disruption of soil macroaggregates (Islam, Weil 2000), pesticides (Mitra, Raghu 1998, Tu 1991), pesticide breakdown products (Cernakova, Zemanovicova 1998), inorganic pollution arising through fertilisers, fungicides and sludge application (Merry et al 1986, Gong et al 1997), the use of fertilisers (Stamatiadis et al 1999) and non-pesticide organic pollution including surfactants (Wilke 1997). Other causes of reduced soil health can arise through water and wind erosion (Garcia et al 1997), and loss of organic matter due to fire, deforestation and tillage (Islam, Weil 2000).

The north-eastern corner of New South Wales is an area rich in subtropical agriculture. Principal crops include macadamia, avocado, sugarcane, banana, pasture and other mixed horticulture. The current soil health project being carried out by NSW Agriculture and Tuckombil Landcare group is driven by concerns among growers about the economic and environmental sustainability of horticultural enterprises and the loss of soil health.

The project described in this manuscript has two key objectives: to assess the health of horticultural enterprises in northern NSW, and to develop technologies to rehabilitate soil health where decline in measured.

Farm soils survey

Fifteen farms were selected to cover a range of enterprises in north-eastern NSW. Five industries, including avocado, banana, macadamia, coffee and sugarcane, with some certified and operating as organic farms, were selected for sampling. Each farm had four sampling sites and two control sites. Control sites were areas that comprised a similar soil type and similar microclimate, but were not influenced by recent agricultural practices. Often, control sites consisted of natural vegetation. For orchard crops, two sites were located beneath the trees, and two sites were between rows (interrow space). For crops such as sugarcane, two sites were located on the mounds beneath the plants and two sites were located between the mounds. Each soil core was subdivided into 0-5cm and 5-20cm samples, and each plot had four soil cores taken.

Soil health tests

Many tests exist for the assessment of soil health. Some of the more rudimentary analyses were performed in this survey to enable a large number of sites to be analysed. These tests included microbial activity, pH, bulk density, water holding capacity and moisture. On eight of the 15 farms, microbial biomass carbon was also determined.

Soil pH, moisture, water holding capacity and bulk density were determined using the methods described by Alef and Nannipieri (1998). Soil microbial activity was determined by two methods; hydrolysis of fluorescein diacetate and alkaline phosphatase. Hydrolysis of fluorescein diacetate was assayed using a modified method described by Zelles et al (1991), Fontvieille et al (1991) and Schnurer and Rosswall (1982). Alkaline phosphatase was based upon the method for assay of acid and alkaline phosphatase in soils described by Tabatabai (1982). Biomass carbon was analysed by methods described by Islam and Weil (1998).

Farm survey results

Comparisons were made between the samples taken from the farm and the control sites. Statistical analysis has shown that on many farms, the level of fluorescein diacetate hydrolysis, alkaline phosphatase activity and microbial biomass were significantly reduced. A summary of these findings is shown in Table 1.

Table 1. Summary of findings from survey of farm soils compared with undisturbed soils

Farm	Interpretation of alkaline phosphatase data	Interpretation of fluorescein diacetate data	Interpretation of biomass carbon data
avocado 1	no differences	no differences	no data
avocado 2	no differences	no differences	no differences
avocado 3	significant increase in surface soil interrow	significant increase in interrow surface soil.	significant decrease in soil in row and in soil at depth interrow
avocado (organic)	significant increase in surface soil in row	no differences	significant decrease in soil at depth
macadamia 1	no differences	no differences	no data
macadamia 2	significant decrease in surface soils	no differences	no data
macadamia 3	significant decrease	significant decrease	significant decrease in soil at depth
macadamia 4	no differences	significant decrease in interrow soil and at depth in row	significant decrease in soil in row
macadamia (organic)	no differences	no differences	significant decrease in surface soil interrow
banana 1	no differences	significant decrease in interrow surface soil.	no data
banana 2	no differences	no differences	significant decrease in surface soil interrow
banana 3	no differences	no differences	no data
sugarcane 1	significant decrease at surface	significant decrease at surface	no data
sugarcane 2	no differences	significant decrease	significant decreases
coffee	no differences	significant increase in depth in row.	no data

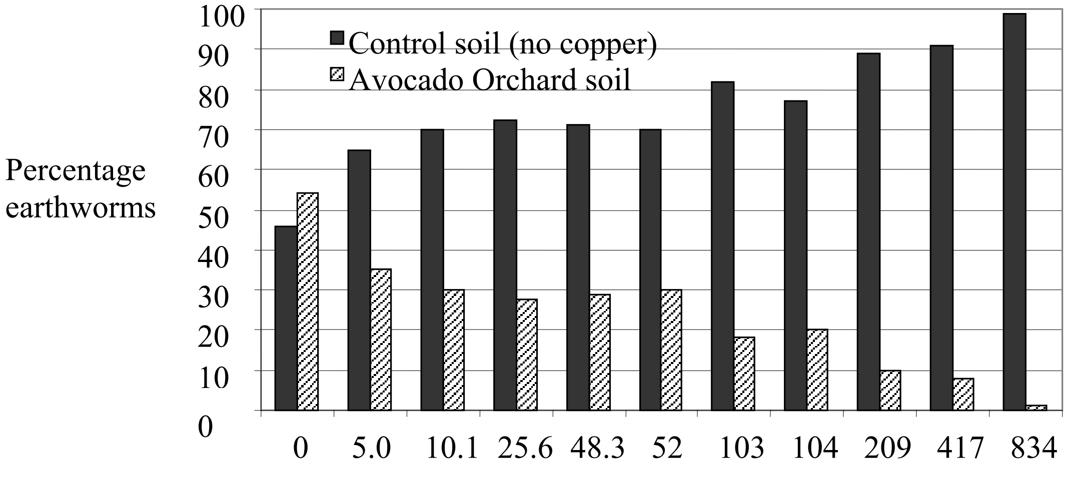
The interpretation of the data shows a decline in soil microbial activity and biomass carbon at a number of farms. Assessment of biomass carbon was a more sensitive measure of damage to soil health, as every farm tested had a significant decline. Control sites are the only acceptable reference for comparing farm data in established agricultural enterprises, as they have developed a natural sustainable biological community. Five of the 15 of farms also had statistically significant decreases in the level of fluorescein diacetate hydrolysis, while only two farms showed an increase. A greater level of fluorescein diacetate hydrolysis does not necessarily reflect a greater level of microbial biomass, as activity and total biomass are independent entities. Three of the 15 farms had decreases in alkaline phosphatase activity, while again two showed an increase.

Earthworm tests

During the 15-farm survey, there were suggestions that certain farms had a severely depleted population of earthworms. This information was gathered during the collection of soil samples, as well as from anecdotal evidence from farmers. Further evaluations of earthworm populations (Tim Kingston, pers. comm) have demonstrated significant declines in earthworm populations in orchards with a history of copper use. To determine whether impacts of fungicidal copper on earthworms exist, avoidance trials were set up using methods outlined by Yeardley Jr et al (1996). The basis of these trials is to count the location of adult worms that have the choice to live and feed in either a contaminated soil or a non-contaminated soil with similar properties under controlled environmental conditions.

Multiple replications of the avoidance trials strongly suggest that copper residues have a significant influence on the presence of earthworms in soil. Figure 1 demonstrates that even with concentrations at 10mg/kg, significant avoidance occurs. When copper concentrations reached 200mg/kg, 90% of the worms were avoiding the soil, while at 800mg/kg, almost complete avoidance was found. No other correlations with soil analyses could be found.

Figure 1. Earthworm avoidance of copper contaminated orchard soil.



Rehabilitation trials

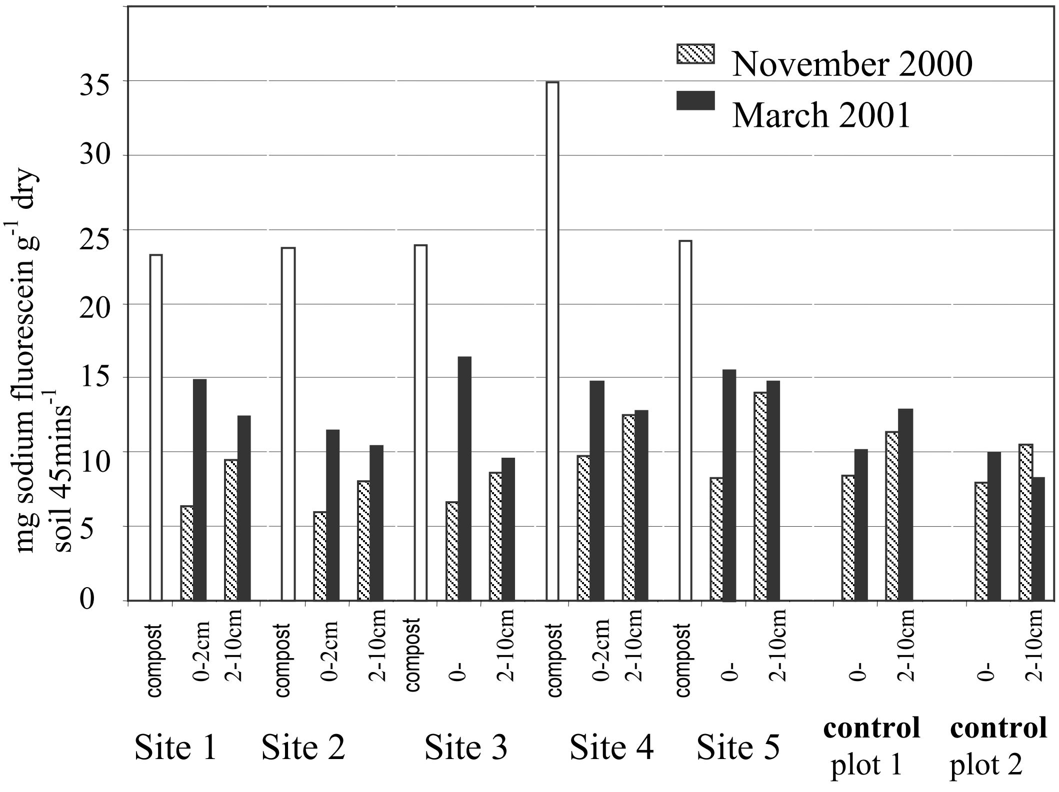
Rehabilitation technologies to improve microbial activity and soil health are not new. These may include the addition of manures, fertilisers, lime and gypsum, and organic materials to soil; and the use of crop rotations, green manures and fallows. In fact, most farmers, both organic and conventional are currently practising some form of soil rehabilitation. What is lacking, however, is a thorough understanding of how these processes benefit the soil biology, to promote soil health. For example, in an Australian vegetable cropping trial which received high inputs of compost, improvements that were observed included higher organic carbon content, greater microbial activity and biomass, greater exchangeable nutrient cations, and greater water holding capacity and aggregate stability (Wells et al 2000).

A composting process was developed at pilot scale to convert farm wastes, including macadamia husk and chicken litter, into a soil conditioner. A pilot system was initially set up according to Van Zwieten et al (1997). Following this, a field scale demonstration was established at a commercial macadamia farm with degraded soil health. The farm had evidence of erosion and decline in soil physical properties, and reductions in biological activity and biomass were measured. Here, 40m^3 of chicken litter was composted with 60m^3 of macadamia husk. The compost remained thermophilic for more than eight weeks, and the pile was turned three times in this period. Water had to be added to the compost pile, as the moisture level dropped below 50% w/w on a number of occasions. The final compost was spread on an area of the farm which was prone to erosion, and where obvious soil loss had exposed surface roots. The addition of the compost did not affect the farm’s standard management practices, as neither sweepers nor nut harvesters were hindered by the presence of the 100mm thick compost layer.

More recently, the composted farm waste described above and commercial compost sourced from Coffs Harbour have also been applied to areas within a three year old macadamia orchard at NSW Agriculture’s Tropical Fruit Research Station, Alstonville to further evaluate organic matter addition and improvements in soil health. Some treatments had coconut fibre matting placed on top of them to act as a weed mat, to further reduce the risk of soil erosion. A ground cover (pintoise peanut) was used in conjunction with the commercial compost in some treatments.

The addition of compost on the commercial macadamia farm gave promising results with improvements in water holding capacity (results not shown) as well as quite dramatic increases in microbial activity, measured by the hydrolysis of fluorescein diacetate (Figure 2). The data shows the level of microbial activity before the application of compost in November 2000, and the increase in microbial activity by March 2001. Compost addition was even beginning to influence microbial activity deeper in the soil profile. The compost layer had a very high level of activity, which is likely to decrease as the organic matter becomes incorporated into the soil. Other plots nearby the area with no compost addition showed very little variation in the levels of microbial activity at the two sampling times. Sampling at both this site and the Alstonville site is continuing.

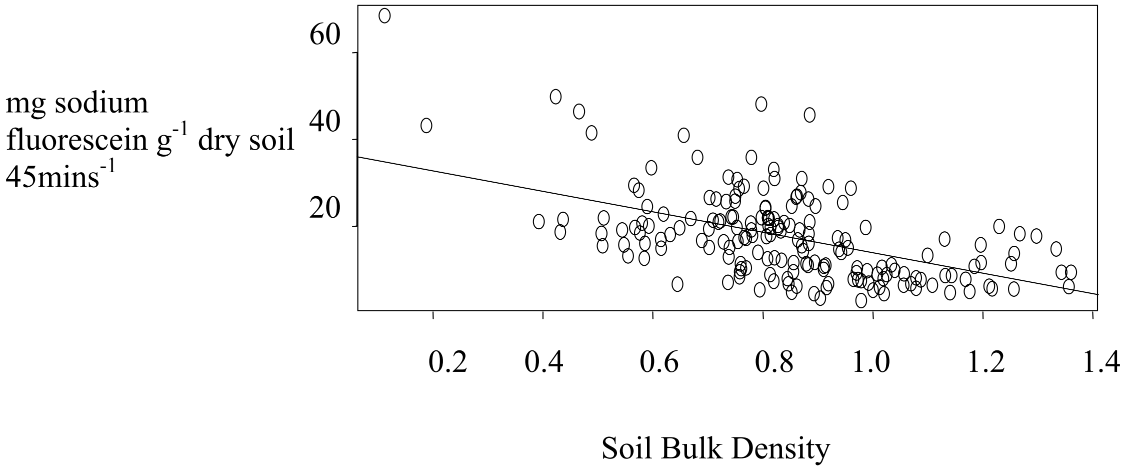
Figure 2. Influence of composted farm waste on soil microbial activity.



North coast soil health

The results of the farm survey show significant decreases in microbial activity in the region's horticultural soils. Trials indicate that the major causes include the presence of copper in soil and increases in bulk density of the soil. Figure 3 shows a general decline in microbial activity as bulk density increases.

Figure 3. Soil bulk density impacts on fluorescein diacetate hydrolysis.



The causes of this increased bulk density include the use of machinery and, in particular, the use of machinery over bare earth, as is common within commercial macadamia plantations. The bare earth is a result of management practices that promote the use of herbicides to keep the under-tree area free of vegetation. This is done principally to facilitate mechanical harvesting of dropped nuts from the orchard floor.

Research results to date have shown that chemical residues in soil and other management practices can influence the microbial activity and microbial biomass in soil. Furthermore, earthworm activity is reduced in soils with copper residues, resulting in reduced bioturbation and incorporation of organic matter through the soil profile.

The question can be asked whether these soil health indicators will affect the sustainability of the industry in question. This question cannot be fully answered yet, although outcomes such as significant soil erosion do suggest that sustainability is compromised. As for the future, multi-disciplinary research teams need to assess and understand soil biology, along with soil chemistry and soil physics, to understand soil health. This could be the first step towards developing truly sustainable systems. Research in north coast horticulture needs to further evaluate the impacts of copper contamination on soil health, and to develop technologies to reduce copper toxicity in soil if soil health is to be improved. Research needs to prove the benefits of this improved soil health, either by increases in yield or produce quality, and reduced inputs or reduced losses due to pathogenic attack. A more detailed study of organic farming systems and commercial soil amendments is needed to evaluate the benefits of these products or practices, and to gather information that will benefit best practice conventional enterprises.

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Organic agriculture soil health strategies

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Organic farming is agricultural production without the use of synthetic fertilisers, chemicals and growth regulators (USDA 1980). Concerns over the environmental impacts of agriculture, declining terms of trade, reduced market opportunities and human health concerns have increased interest in the adoption of organic farming systems.

Historical development

By the late 1800s the combination of the industrial and scientific revolutions had resulted in undeniable benefits for agriculture and society. The industrial revolution gathered people in larger cities and made greater demands on agriculture for food and fibre, while the scientific revolution saw the development of modern scientific method and the growing importance of technology and engineering. This period (1850-1930) also saw the emergence of the biological, or life, sciences and the earth sciences. While these did not have as visible an effect as chemistry and technology, the findings of individuals such as Darwin (1881), Frank (1885), Rayner (1927), King (1911), Hilgard (1906) and Hopkins (1910), were important for the development of modern organic agriculture.

During the 1930s, agricultural practices came under scrutiny as vast areas of agricultural land in the USA became subject to wind erosion during what became known as the ‘dust bowl’ period. This led to the establishment of numerous soil conservation projects and agencies. Researchers found correlations between a decrease in soil health and an increase in degenerative diseases, reproductive problems, and a general decline in health among humans and animals (Wrench 1938, USDA 1939, Price 1945).

By the early 1940s there were indications that agriculture was beginning to balance its chemistry with biology, and its technology with ecology. A more holistic approach was permeating the thinking of both farmers and agricultural scientists. Some of the most significant soil researchers of the time included Jacks and Whyte, 1938; Howard, 1943; Cocannouer, 1950 and 1958; Hendricks and Alexander, 1957; Kellog, 1957; Russell, 1973; Albrecht, 1975; and Balfour, 1976. The research of these individuals highlighted the complexity of soils, particularly in the area of soil organisms and their relationships to plant health and growth. Research also investigated the nature and effects of crop rotations on soil fertility (Leighty 1938) and the importance of humus to a healthy soil (Waksman 1936, Howard, 1943).

During the 1950s there was a definite shift back to a predominantly chemical and technological approach. For the next twenty years, holistic and integrative research declined as scientists lost interest or could not attract research funds.

Many attributed this shift to a post World War II surplus of products and technology from petrochemical and munitions industries. It was during this period that the 'organic' versus 'conventional' agriculture debate reached its peak. The publication of Rachel Carson's *Silent Spring* in 1962 saw the debate shift in favour of organic agriculture. Carson's research highlighted the impact of pesticides on the environment and pointed to the inevitable decline in ecosystem health. Carson stressed the interrelatedness of all life on the planet, that each species has its own ties to others, and that all are related to earth.

By 1977, as erosion and declining soil fertility were reappearing as serious problems in agriculture, the United States Senate was preparing to hold hearings on the relationships between diet, disease and health, and researchers began re-visiting agro-ecology. At the farm level, organic agriculture emerged as a movement offering farmers an alternative to expensive biocides and energy intensiveness and which aimed to minimise the impact of agriculture on the environment and work with nature.

Today, as agriculture struggles to find a balance between feeding the world and managing legacies such as salinity, soil acidification, declining bio-diversity, pesticide resistance and human and animal health concerns, a renaissance in integrative thinking is permeating agricultural policy and research. Researchers are beginning to investigate organic farming systems in the hope that they may provide some solutions to improving agricultural sustainability. As consumers begin to demand food that is produced with minimum impact on the environment and with minimum pesticide application, the organic industry is experiencing an annual growth rate of 30%. This expansion far exceeds that of any other agricultural sector.

Soil – the foundation of organic philosophy

Organic farming's basic tenet is the creation of a healthy, fertile soil as the basis of the farm agro-ecosystem. The concepts of the Living Soil and the Law of Return are fundamental principles of organic agriculture.

The 'aliveness' or dynamic nature of soil is intrinsic to organic agriculture. Organic proponents often equate the quality of soil with the level of health of plants and animals, and, in turn, humans living on that soil. Organic farming is primarily a soil building process. Relevant to this is the belief that without an understanding of the soil as a living, dynamic entity, and without an intimate working relationship with the soil, soil building will not occur, and a sustainable self-sufficient agro-ecosystem able to produce basic food requirements will be unattainable.

The Law of Return, in its simplest meaning, says that 'all life forms must return at death what they took from their resources during their life time' (Farmer 1977). This statement recognises the cyclic nature of the earth's natural processes. Refusal to recycle biological wastes back into the soil deprives microbial decomposers of their food supply, which in turn prevents the release of essential nutrients by decomposers. Organic philosophy takes this concept one step further by likening the export of agricultural commodities to irretrievable loss of soil nutrients. Hyams (1976) and Carter and Dale (1974), note that the continuous export of agricultural products played a definite role in the destruction of the once fertile North African soils. In addition, full compliance with the Law of Return would require a more even distribution and intermingling of urban and agricultural lands and subsequently greater contact between urban and agricultural people. Many advocate that in the long run this would lead to a better balance between agriculture and industry, and build a more humane and holistic society (Merril 1983).

The organic soil building process

There is worldwide agreement within organic standards that organic farming systems should maintain or increase soil fertility on a long-term basis. Australia's organic standard, The National Standard for Organic & Bio-dynamic Produce (1992, 1998) states that the primary aims of organic agriculture include:

- producing food of high nutritional value
- enhancing biological cycles in farming systems
- maintaining and increasing fertility of soils
- working as far as practicable within a closed system
- avoiding pollution resulting from agriculture
- minimising the use of non-renewable resources
- coexisting with, and protecting the environment.

These aims are achieved through management practices that enhance soil biological activity so that plants are fed through the soil ecosystem and not primarily through soluble fertilisers added to the soil. Organic farming systems rely to the maximum extent feasible upon crop rotations, crop residues, animal manures, legumes, green manures, mechanical cultivation and approved mineral-bearing rocks to maintain soil productivity and tilth and supply plant nutrients.

Conversion from a conventional fertiliser regime to an organic soil building process involves eliminating the use of artificial chemicals in the farming system. This means that fertilisers such as superphosphate and ammonium nitrate are excluded and replaced by practices which foster the cyclic renewal of nutrients to maintain crop health.

Organic matter content, microbial activity and general soil health are taken as measures of soil fertility. An analysis of organic farming systems in Europe (Stolze et al 2000) has found that organic farming increases microbial activity by 30-100% and microbial biomass by 20-30%. A comparative study of organic, conventional and integrated apple production systems in Washington State from 1994 to 1999 found that organic and integrated systems had higher soil quality and potentially lower negative environmental impact than the conventional system. The data indicated that the organic system ranked first in environmental and economic sustainability, the integrated system second and the conventional system last (Reganold et al 2001).

Research into the sustainability of organic farming systems in Australia has been limited, and has tended to focus on comparative studies in extensive cropping and livestock systems, systems characterised by their low use of external inputs.

Phosphate rock, lime, dolomite, legume rotations, incorporation of green manures and crop refuse, manure application during livestock grazing, and the application of microbial preparations may be used for building soil fertility. Studies by Penfold (1995), Derrick (1996), Derria et al (1996) and Schwarz (1999), suggest a trend towards deficiencies in phosphorus, nitrogen and sometimes sulfur, under current organic management regimes in broadacre (extensive) cropping and livestock systems.

Limited studies of intensive organic farming systems in Australia have generally shown an increase in soil health compared with conventional practice (Wells, Chan 1996, Huxley, Littlejohn 1997, Stevenson, Tabart 1998). This could largely be a reflection of the cost effectiveness of applying larger applications of commercial organic fertilisers, compost and incorporation of green manures to high value crops such as fruit, vegetables, and herbs.

Organic soil building practices

Organic farmers have a range of options to sustain soil health. Applications of these methods are discussed below.

Increasing biological activity

Organic conversion begins with a process that encourages increased microbial and arthropod activity within the soil. The elemental composition, structure, and organic matter content of the soil need to be favourable if soil biological activity is to be enhanced. Biological activity begins with the breakdown of soil organic matter. During the decomposition process, the organic molecules in organic matter are broken down into simpler organic molecules that require further decomposition into mineralised nutrients. Organic farmers supply organic matter through incorporation of green manure crops and crop refuse, and the addition of compost.

The use of bio-indicators is becoming an increasingly important way to assess soil health. Pankhurst et al (1997) review the measurement of soil organisms and biotic processes as indicators of soil health. A range of techniques is available to assess soil biological activity. These include measurement of CO_2 respiration; DNA testing to determine the diversity and abundance of microorganisms present; and measurement of the tensile strength of cotton strips buried in the soil. Commercial laboratories offering soil microbial assessment are now becoming more common in Australia.

Green manuring

Green manure crops are grown specifically to be cultivated back into the soil to build up soil organic matter and nutrients, and to stimulate biological activity. The type of green manure crop and stage at which it is turned in determine the amount of organic matter or nutrients returned to the soil. A lush, actively growing sward of legumes such as vetch, faba beans or lupins contains large amounts of nitrogen (50-140 kg N-gain/ha) that is released to the soil upon cultivation. The same crop, when allowed to mature, contributes more organic matter but less available nitrogen. If a soil is low in organic matter, then a green manure crop that increases soil organic matter, such as oats, is desirable.

Plate 1. Green manure crops of oats, faba bean and vetch at NSW Agriculture's organic demonstration site at Yanco. Photo: R. Neeson.

Green manures may also act as break crops to reduce the carryover of pests and diseases in subsequent crops in the rotation. Green manure crops are an essential component in intensive organic annual cropping rotations.

Nitrate leaching following the incorporation of a green manure crop may occur when rainfall exceeds evaporation resulting in net drainage. There is some evidence to suggest that nitrate leaching may be less under organic than under conventional systems (Lampkin 1990). Nitrate leached below the root zone is effectively lost from the system. Rotation design within the organic system needs to consider how large nitrogen losses following the ploughing in of the green manure crop can be minimised. Early establishment of a cereal crop immediately following incorporation of green manure has been shown to be the simplest and one of the most effective methods of reducing nitrate leaching.

Undersowing crops

Undersowing of crops is a key practice in organic systems. One example is barley undersown with the grass/clover pasture that will follow in the rotation in the succeeding year. This practice has been shown to have beneficial effects on the diversity and abundance of insect species (Vickermann 1978). Other benefits include the potential for higher protein content in cereals undersown with a legume, due to a small net nitrogen gain, enhanced weed suppression and improved pest and disease control (Lampkin 1990).

Plate 2. Lucerne undersown eight weeks after maize emergence comes away following maize harvest. Yanco organic demonstration site. Photo: R. Neeson.

Growing permanent swards and pastures

In livestock and cropping enterprises, legume-based pastures provide the systems' major nitrogen input. Livestock largely recycle other nutrients. In orchards, permanent swards (sods) are sometimes planted between the rows, and are the preferred method of interrow management because the soil ecosystem remains undisturbed. This favours the development of plant roots, soil microfauna and flora, worms, and mycorrhiza, and helps retain good soil structure.

A mixture of deep-rooted and shallow-rooted species increases the potential for accessing soil nutrients. For example, in organic pastures, herbs such as chicory, plantain, yarrow and caraway are often added. Ideally, an orchard sod consists of a range of perennial plant species. Grasses such as ryegrass or fescue are efficient in obtaining potassium from the soil and able to utilise excess organic nitrogen. Legumes such as clover or lucerne may contribute 40–140 kilograms per hectare per year of nitrogen to the soil reservoir. Herbs such as comfrey and chicory often have a higher mineral content and have deep roots capable of bringing up leached elements that would otherwise be unavailable to the crop.

A study by Evans et al (2000) of organic cropping systems in the Riverina and Central West of NSW will attempt to identify best practice for management of the pasture phase to optimise soil microbial activity and increase soil concentrations of mineralised nutrients. The study aims to quantify soil fertility trends and will introduce a range of innovative pasture management practices to improve yield and cropping frequency.

Plate 3. A range of deep-rooted and shallow-rooted species (oats, faba beans and rape) in green manure crops increases the potential for accessing soil nutrients and improving soil structure. Photo: R. Neeson.

Applying compost

Compost is a primary source of nutrients and organic matter in intensive organic farming systems and an invaluable food source for soil microorganisms. The use of compost in Australian broadacre organic cropping systems is not widely practised, as its application is not cost effective. Animal manures and crop refuse form the major ingredients of compost. Organic standards require that manure intended for application is composted before use.

The major benefits of compost are that it is a more stable form of organic matter than raw waste, and weed seeds and diseases are destroyed during the composting process. When manure is composted, it is easier to spread, and losses to the environment are minimised. Rock dusts and clay, added to compost in small quantities, may help to reduce nitrogen losses from the heap by absorbing ammonia (Lampkin 1990).

There are many recipes and techniques advocated for composting. The Australian Standard for Composts, Soil Conditioners and Mulches (AS 4454-1999) defines composting as ‘the process whereby organic materials are pasteurised and microbiologically transformed under aerobic and thermophilic conditions for a period of not less than six weeks’. The pasteurisation process is described as having ‘the whole mass of constantly moist material subject to at least three consecutive days at a minimum temperature of 55°C’.

The major aim of composting is to produce a stable humic compound. This is achieved by mixing major ingredients together in quantities that achieve a suitable carbon:nitrogen ratio. The ideal C:N ratio lies between 25 and 35:1 (Lampkin 1990). Moisture content is also important and ideally should be in the order of 55-70%. Compost heaps should be designed to allow for sufficient air access. Microbial activity quickly raises the temperature of the heap to above 55°C, after which it is turned (ASA standards specify a minimum of three turns) to allow for thorough mixing and a further heating of any undecomposed material.

Plate 4. Compost production at NSW Agriculture organic demonstration site, Yanco. Photo: R. Neeson.

Remineralising the soil

Many Australian soils are leached of elements essential for plant growth. Moreover, many years of farming with emphasis on supplying a nitrogen, phosphorus and potassium fertiliser regime at the expense of minor elements may have resulted in further ‘mining’ of certain trace elements. This theory has some support, with evidence (McCance, Widdowson 1940-2000) suggesting a gradual decline in the elemental composition of fresh fruit and vegetables since the 1940s.

Soils with higher biological activity play an important role in increasing the availability of micronutrients. Significant research has been undertaken in the symbiotic roles of arbuscular mycorrhiza fungi in increasing phosphorus availability in plants and rhizobium bacteria, and its ability to fix atmospheric nitrogen for plant use. However, little research has been undertaken into the role of other soil microorganisms in improving micronutrient uptake by plants.

The remineralisation of Australian farming soils is a more recent strategy proposed by some soil health practitioners. Various techniques for remineralisation have an increased following amongst farmers, largely based on balancing the CEC of soils and achieving a satisfactory calcium to magnesium ratio (Albrecht 1975). The effectiveness of these techniques is yet to be scientifically evaluated under Australian conditions.

Remineralisation involves the addition of various fertilisers of mineral origin. These are rock-based materials and include rock phosphate, dolomite, limestone and rock dusts from silicate rocks, including basalt and bentonite and some commercial organic blends. Rock dusts may be added directly to the soil or added to compost heaps. Whichever method of application is favoured, release of nutrients from the rock dusts is accelerated by moist conditions, high temperatures and high biological activity, for example, during a green manure stage or composting.

Improving soil structure

Improvements in the biological activity and CEC of soils will generally lead to an improvement in soil structure. However, this needs to be supported by suitable cultural practices. Use of appropriate machinery at correct soil moisture, incorporation of soil organic matter, and improvement of soils utilising different crop root physiology are techniques used by organic farmers to develop soil structure.

Lampkin (1990) describes cultivation practices as having the most significant impact on the soil of any agricultural activity. He summarises the organic approach to soil cultivation as one that seeks to maintain soil structure and allow the soil to have vegetative cover for as long as possible within the rotation. Shallow cultivations, where only surface layers of the soil are mixed, are an important element of this approach. Deep cultivation of dry soil is practised to loosen and aerate soil, avoiding inversion of the lower layers. Green manures or cereal crops are sown as soon as practicable following cultivation, their roots helping to stabilise loosened soil and minimise nitrate leaching.

Organic soil conversion

Organic conversion is not just about replacing a high-input chemical system with a no-input system. I propose that the organic soil building process goes through three critical stages. For the purpose of this paper I will refer to these as the adjustment phase, the comfort phase and the maintenance phase.

Adjustment phase

The adjustment phase involves developing a system that reduces the crop's reliance on artificial chemicals. This could be likened to overcoming ‘cold turkey’ for those farming systems that are heavily dependent on chemical inputs. During this phase some farmers have observed that crop yields may decline as the system converts from a chemical to a biological one and is starved of its regular ‘fix’ of readily available, chemical fertilisers.

The length of this preliminary soil building process will depend largely on the soils’ pre-existing condition. The adjustment phase involves increasing biological activity by providing optimal soil conditions. The challenge for the organic farmer is to implement a cost-effective strategy that encourages and builds biological processes within the soil while maintaining optimal plant nutrition. Standard organic practices such as planting of legumes and green manures, and applications of compost, rock dusts and commercial organic fertilisers, are combined with foliar applications of seaweed, fish emulsion, sugar solutions and microbial preparations to stimulate soil biological activity and supplement plant health.

Comfort phase

The comfort phase coincides with an increase in biological activity and a corresponding release of previously 'locked-up' or unavailable nutrients. During this phase optimal crop yields are reached. Organic farmers need to be diligent that over-fertilisation does not occur during the comfort phase. This is more likely to occur in intensive horticulture systems where applications of compost and green manuring are common practice. Evidence of over-fertilisation usually manifests itself through crop physiological problems and increased pest and disease incidence. Organic farmers are encouraged to regularly monitor soil nutrient levels. Soil and plant tissue-testing enables nutrient requirements to be tracked thus avoiding 'overfeeding' the soil system.

Maintenance phase

Research has indicated that some organic systems have, over a longer period of time, undergone a decline in soil nutrient reserves (Small et al 1994; Penfold C et al 1995). This could be attributed to long term drawing down of nutrients during harvesting of crop or livestock products and through natural processes such as leaching. In Australia, this has been particularly evident in broadacre cropping and livestock enterprises where phosphorus deficiency has been found. This has implications for cereal and legume crops. Phosphorus deficiency in legumes will impact on plants' ability to fix atmospheric nitrogen in root nodules. Nitrogen fixed by legume forms is an essential nutrient in subsequent crops in the cropping rotation. Nutrient budgeting by reconciling inputs and outputs to the soil system and correlating these with regular soil tests and crop performance can help organic producers track the performance of the soil nutrient cycle.

Correcting deficiencies

Unseasonal weather conditions, such as a prolonged dry spell or excessive wet, or just a miscalculation of crop nutrient requirements, may result in a deficiency within the crop. If this happens during a critical crop growth period, plant health may decline, predisposing crops to pest and disease attack. A permanent yield depression may result, so it is necessary to correct any deficiency quickly. Leaf analysis is the usual method to detect deficiencies during the crop growing period. Organic farmers make use of foliar sprays such as fish and seaweed extracts, molasses and trace elements to correct temporary deficiencies.

Case study: organic conversion at Yanco

At Yanco in the Murrumbidgee Irrigation Area in southern NSW, NSW Agriculture, in conjunction with the Natural Heritage Trust's National Landcare Program, has established a demonstration site to illustrate the organic conversion process to farmers. Practices demonstrated include:

- increased soil fertility and biological activity by
    - use of legumes, green manure and other crops in appropriate rotations
    - application of composts, special preparations and other organic and mineral fertilisers
- various tillage techniques
- non-chemical methods of pest, disease and weed control
- evaluation of crop varieties for pest and disease susceptibility and adaptability to diverse, low input cropping systems.

Planting on the four hectare site is designed to achieve sustainable production and maintenance of soil health through rotation of cereals, oil seeds, legumes and vegetables. The entire site was sown down initially to green manure crops which were then incorporated in the soil. Two organic soil treatments were then applied. Both treatments comply with organic standards.

Soil treatment A is referred to as ‘organic - biodynamic’. In this treatment, crops are fertilised pre-sowing with compost and rock phosphate and foliar applications are applied after six weeks at intervals of eight to ten days, depending on leaf analysis results. The foliar applications consist of biodynamic preparation 500, biodynamic fish emulsion, brown sugar, worm liquid and seaweed liquid.

Plate 5: NSW Agriculture technical officer Tobias Koenig inspects linseed at the Yanco organic demonstration site. Photo: R. Neeson.

Soil treatment B follows a remineralisation strategy that aims to achieve a satisfactory calcium to magnesium ratio. In this treatment the same organic-biodynamic fertilisation program is followed with the addition of small, pre-sowing applications of lime (up to 300 kg/ha) and gypsum (up to 500 kg/ha) as per soil analysis results.

The project, now in its fourth year, has been evaluating soil and crop health in both treatments. A diverse range of crops has been grown, including wheat, oats, sunflowers, linseed, safflower, sweet corn, maize popcorn, soybeans, pumpkins, melons, tomatoes, lettuce, and green manures. Marketable yields have been achieved for most crops, although in most instances yields are below the district average. Soybeans have been the exception with crop failures due to significant green vegetable bug damage. *Heliothus* spp. has been the other major insect pest, and while some minor crop losses did occur, pest populations were manageable. Disease incidence has been negligible on all crops.

Standard soil analysis has been carried out each year, before and after planting. Soil analysis trends show that organic matter has increased from 1.5% to 3.0%, pH has generally remained unchanged at 7.3, the calcium-magnesium ratio has increased from 1.7 to 2.5, and the cation exchange capacity decreased slightly, due largely, it is believed, to an increase in potassium from compost applications.

The real benefit of organic management at Yanco will be to demonstrate the long-term impact of the intensive organic rotation. Soil health improvement, pest and disease incidence, sustainable crop yield and quality, will continue to be monitored over the coming years to assess these changes.

The primary aim of the Yanco demonstration site has been to show farmers that organic practices can be sustainable and that some practices may offer opportunities for conventional farmers to reduce chemical inputs. This is being achieved, with some Riverina district farmers now practising organic management of corn, soybean and vegetable crops. Alliances between local processors and producers are being forged, enabling producers to investigate opportunities in lucrative organic export markets.

Conclusion

Maintaining soil health organically relies on nurturing the soil's biological and mineral processes. Incorporation of green manures and legumes in the cropping rotation, applications of compost, mineral rock dusts and organic fertilisers, and grazing of livestock combined with appropriate tillage are some of the techniques used by organic farmers to meet this objective.

More research is required under Australian conditions to determine organic soil management strategies for optimum crop performance and to assess the effectiveness of current practice. Essential to this research is gaining a better understanding of the relationships between soil microorganisms, soil and plant health, including mineral uptake, and pest and disease resilience.

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Soil organic carbon and soil structure: implications for agro-ecosystem soil health

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Soil organic matter, the organic fraction of the soil, is a complex mixture of plant and animal products in various stages of decomposition, and soil microbes and substances produced by them. Many Australian soils are inherently low in soil organic carbon (Spain et al 1983). The latter authors estimate that approximately 75% of Australian soils now contain less than 1% of soil organic carbon in their surface horizons. However, many of these soils, including the red-brown earths, solonised brown soils and the grey, brown and red clays, are important for Australian agriculture.

Soil organic carbon influences all three aspects of soil fertility, the physical, chemical and biological (Dalal, Chan 2001). It therefore plays a controlling role in soil quality and, as such, affects the productivity and the sustainability of farming systems. In this paper, the main focus is on the importance of soil organic carbon (SOC) in maintaining good soil structure (soil physical fertility), a pre-requisite for a healthy agro-ecosystem. The complex but important interactions between soil structure and soil biological fertility as affected by soil organic carbon will also be highlighted.

Soil organic carbon and soil structure

Soil structure is defined as the size, shape and arrangement of aggregates and the voids in between, in a soil at a given time. It is the architecture of the soil and can be described both in terms of the pore system as well as the arrangement of primary soil particles into hierarchical structural states (Kay 1990). Soil structure provides the physical spaces or ecological niches for many soil organisms. Moreover, the interactions of the soil structure with soil water content determine a number of important soil physical properties that in turn define the physical environment of the soil ecosystem. These properties include soil water availability and soil water permeability, soil aeration and soil mechanical properties (Smiles 1988).

It is important to realise that soil is the habitat for a range of living organisms that make up a healthy agro-ecosystem (Lee, Foster 1991). The architecture and the physical environment of soil structure determine the types of organisms that can exist in a particular soil (diversity), their abundance and their activities. These are important factors that affect the functioning of the soil as an ecosystem and determine the ‘health’ of the soil.

For instance, soil structure determines soil moisture levels and the moisture stress that organisms are subjected to at a particular soil water content. For plants, the limits are field capacity (-10 kPa) and permanent wilting point (-1.5 MPa). This range is commonly known as water holding capacity and it varies according to soil structure or porosity. Soil moisture characteristics also control the mobility of many small soil animals such as nematodes, motile bacteria and aquatic phycomycetes which are restricted to existing water-filled soil pores. These organisms depend on sequences of water-filled pores of the right size to permit their passage (Papendick, Campbell 1985). The rate of water movement through soil, determined by pore size distribution, controls many important biological activities such as wilting and germination of plants, and hatching of nematode cysts (Smiles 1988).

At the same time, the composition of soil atmosphere is governed by gaseous diffusion processes between the above ground atmosphere and the soil which depend, in turn, on the soil's porosity. As a result, aerobic and anaerobic zones are interspersed throughout the soil and these also affect the prevalence and distribution of organisms in soils.

According to Dexter (1988), a soil that provides an ideal medium for crop production needs well-developed structural form, stability in the face of water and external mechanical stresses, and resilience or the ability to recover its structure after disturbance (Kay 1990). Soil organic carbon affects all three aspects of soil structure - form, stability and resilience (Kay 1997).

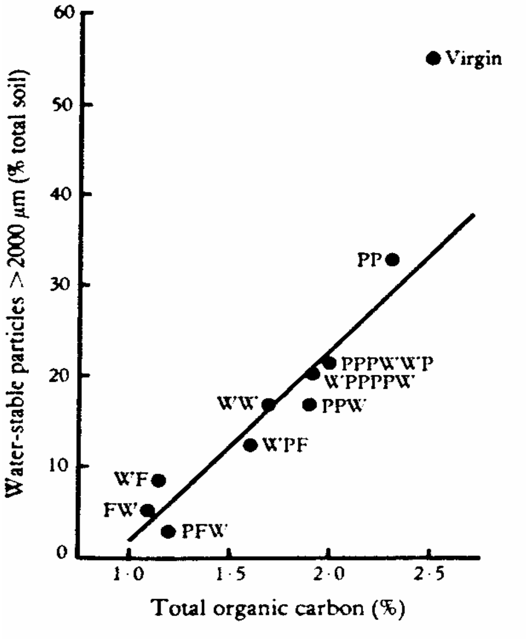
Role of soil organisms

While many soil organisms live in and depend on existing soil pores, larger organisms can make new pores and therefore modify soil structure. Plant roots, earthworms and termites fall into this category. The effectiveness of grass roots in producing soil aggregation by drying and wetting as well as by enmeshing actions are well known. Soil fauna such as earthworms and enchytraeids play an important role in creating soil aggregates (worm casts) and macropores (burrows) and hence modifying the pore size distribution. However, their abundance and activity depend on food supply and are therefore closely related to organic matter inputs and soil organic carbon levels.

Structural stability and soil organic carbon

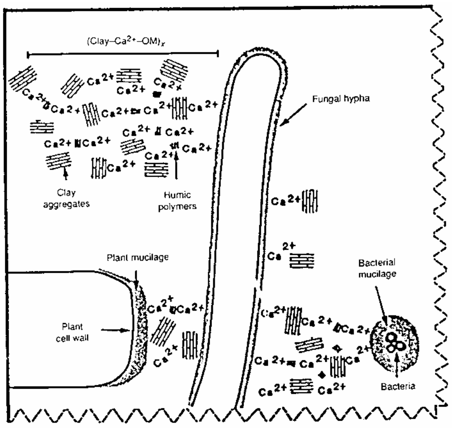
Organic carbon in various forms and in different locations within the soil medium contributes to the stability of soil structure. Results from both Australia (Tisdall, Oades 1980) and overseas (Chaney, Swift 1984) have demonstrated the positive effects of soil organic carbon level on soil structural stability. As shown in Figure 1, soil structural stability increases with increasing organic carbon levels which in turn vary with the frequency of fallowing and pasture in relation to the wheat phase. Fallowing decreases organic carbon levels and therefore has a deleterious effect on structural stability.

Figure 1. The relationship between water-stable soil aggregates and organic carbon under traditional wheat/fallow/pasture rotation (Tisdall, Oades1980). (W = wheat, F=fallow, P=pasture).



Based on the hierarchical model of soil structure, a soil is made up of structural units of different sizes in the following order: domain (clay aggregates), microaggregates and macroaggregates (Tisdall, Oades 1982). Figure 2 presents a schematic model of macroaggregates (>250 μm).

Figure 2. Schematic presentation of a soil macroaggregate (Muneer, Oades 1989).



Different chemical forms of organic carbon are found in different parts of the soil aggregates, acting as binding agents at different levels of soil structure. For example, microorganisms such as fungal hyphae, bacteria and their products exist between microaggregates and act as important binding agents for holding macroaggregates (>250 μm) together. From electron micrograph evidence, it has been proposed that a matrix of particulate organic matter (plant residue), microbial biomass and extracellular materials can attract inorganic particles (clay and silt) and act as centres of water stable macroaggregate formation (Waters, Oades 1991). On the other hand, humic polymers are found in between clay aggregates (domains) and are important in maintaining stability of macroaggregates. Depending on the quality (chemical nature) and physical location within the soil, the different organic carbon fractions tend to have different lability and turnover time (Table 1). The fraction of soil organic carbon that exists in pores within microaggregates is inaccessible to microbial attack and therefore has a relatively long turnover time and is regarded as being physically protected.

Table 1. Turnover time of soil organic carbon depending on quality and physical location within the soil (Lal 1997).

Type of organic matter	**Location**	**Turnover time**	
		Years	Category
microbial biomass	pores, particle/aggregate surface	0.1-0.5	labile
litter	soil surface, pores	1-5	rapid
light fraction	voids, aggregate surface	5-15	moderate
particulate	voids, biopores	5-20	moderate
humus	inter-microaggregate	20-50	slow
humus	adsorbed on intra-microaggregate	50-1000	passive
humus	adsorbed on intra-microaggregate	1000-3000	passive

Soil organic carbon as an indicator of soil health

Conventional tillage

In Australia, significant declines in soil organic carbon have been reported under cropping, particularly when using traditional tillage implements and practices such as stubble burning and fallowing (Dalal, Mayer 1986; Geeves et al 1995). Figure 3 presents the changes in organic carbon in the top layer (0-10 cm) of six Queensland soils after several years of cultivation. It is clear from the data that organic carbon levels tend to decline with time under cropping but at different rates for different soils. Declines tend to follow first order kinetics, occurring rapidly in the first few years then decreasing with time so that the soil organic carbon level approaches a steady value.

Figure 3 Decrease in soil organic carbon in the top 0- 0.1 m layer with the period of cultivation (Dalal, Mayer, 1986). 1 Waco, 2 Langlands-Logie, 3 Cecilvale, 4 Billa Billa, 5 Thallon, 6 Riverview.

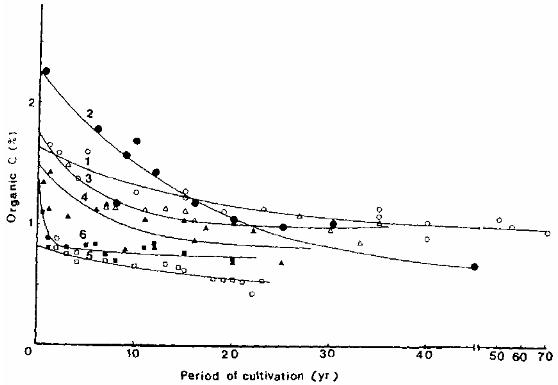
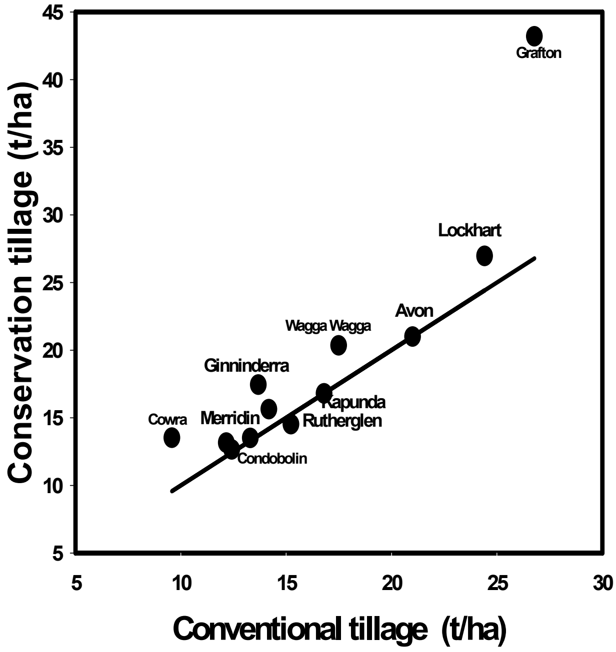


Figure 4. Soil carbon storage (0-10 cm) under conservation tillage compared with conventional tillage at different locations in Australia.



Conservation tillage

A review of soil organic carbon levels stored in the 0-10 cm layer in lighter-textured soils around Australia does not indicate consistently higher levels under conservation tillage when compared with those under conventional tillage (Chan et al 1998). As evident in Figure 4, many of the sites do not deviate markedly from the 1: 1 line with the exception of the Grafton site which is located outside the main cereal cropping zone. The ratio of carbon storage between the two systems was found to be positively related to the annual rainfall (r = 0.76**). This relationship suggests that in the lower rainfall (<500 mm) areas soil's potential as a carbon sink through the use of conservation tillage to sequester carbon is rather limited under the present management. Most cereal cropping in Australia is carried out under rain-fed conditions in areas with annual rainfall of 250-600 mm.

In fact, under broadacre cropping, there is little evidence to suggest that soil organic carbon under conservation tillage increases with time (Heenan et al 1995). Results of a long-term tillage/stubble management/rotation experiment on red earth at Wagga Wagga show that under continuous wheat-lupin rotations, soil organic carbon declined continuously over 14 years under all tillage and stubble management practices (Figure 5). The highest rate of carbon loss (400 kg C/ha/yr) was found under continuous wheat and conventional tillage/stubble burnt. Near equilibrium level was achieved only under direct drill/stubble retained in the subterranean clover-wheat rotation. Little information is available for horticultural crops. However, under irrigated vegetable production, significantly higher soil organic carbon levels were detected in the organic production system compared with the conventional systems after three and a half years due to additional input of organic matter in the form of compost (Wells et al 2000).

Figure 5. Rate of soil organic carbon loss under different tillage and rotation treatments in the long term experiment at Wagga Wagga. DD = direct drilled RT = reduced tillage CT = conventional tillage.

Labile soil organic carbon as indicator of soil structure

For many soils, more than half of the soil organic carbon is in very inert forms with long turnover times, such as charcoal (Skjemstad et al 1996). It is therefore logical to expect that changes in the more labile forms of soil organic carbon are more sensitive indicators of soil quality attributes such as soil aggregate stability.

Microbial biomass

The changes in the quantity and quality of soil organic carbon and the effect on soil aggregate stability as a result of growing different crops in rotation with wheat were investigated on a red earth (Oxic Paleustalf) in Wagga Wagga (Chan, Heenan 1999). After two cycles of the wheat and alternative crop rotation, the total organic carbon in the 0-5 cm soil depth was similar (15.1 g/kg), but there were significant differences in water stable aggregation of soil from the different rotations. Wheat/lupin and wheat/barley rotations were the most stable, followed by wheat/canola and then by wheat/field pea.

Rather than total carbon or other extractable fractions, the observed differences in aggregate stability were only significantly related ($P<0.05$) to microbial biomass carbon. Following the hierarchical model of soil aggregation (Tisdall, Oades 1982), macroaggregates (> 250 μm) created by the different crops were stabilised by microorganisms such as fungal hyphae and their products which made up <2 % of the total soil organic carbon content.

Particulate organic carbon

Changes in particulate organic carbon (POC) relative to total organic carbon (TOC) were measured in soils from five agronomic trial sites in New South

Wales, Australia (Chan 2001). These sites covered a wide range of different land use and management practices. Particulate organic carbon made up 40-74 % of total organic carbon and tended to be higher under pasture and more conservative management than traditional cropping regimes. It was the dominant form of organic carbon accumulating under more conservative management practices such as direct drilling, retained stubble and organic farming. It was also the form of organic carbon preferentially lost when soils under long-term pasture were brought under cultivation. Across all sites, changes in particulate organic carbon accounted for 81.2 % (range 69-94 %) of the changes in total organic carbon changes caused by differences in land use and management. For the Vertisols, particulate organic carbon was found to be a sensitive indicator of both macroaggregate stability and nitrogen availability (Chan 1997).

Conclusions

Satisfactory soil structure is a prerequisite of a healthy agro-ecosystem. Soil organic carbon is important in determining soil structural conditions, acting both as a food supply for the soil structure-forming organisms, and as a stabilising agent. Under broadacre cropping, soil organic carbon levels are low and are continuously declining, indicating a worrying trend of soil structural decline (degradation) and deteriorating soil health. Little information is available for horticultural crops. Soil organic carbon, particularly labile pools, is a sensitive indicator of soil structure and soil health.

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Using soil tests to make fertiliser recommendations that will keep soils healthy and productive

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To farmers, healthy soil means healthy and productive crops, pastures and trees. While farmers aim to make an income, most also want to hand on their soil in as good, if not better, condition than they received it. This paper is a summary of one agronomist's view of what is practical, factual and important for farmers applying fertiliser, lime and gypsum.

Four principles need to be kept in mind to ensure that fertiliser use is economically sound, practical and sustainable.

- A soil test or, in some cases, a plant tissue test, is the basis of reliable decision-making.
- The soil's physical attributes need to be analysed as well as its chemistry.
- The soil is as deep, or deeper, than the rooting depth of plants.
- The soil chemistry balance should not be changed without good reason.

There are two basic philosophies of soil test interpretation used by soil-testing organisations to arrive at fertiliser recommendations. One philosophy works on the feeding the plant, the other on feeding the soil.

Feeding the plant

To assess what the plant needs, the soil is analysed using standard analytical methods. The results are measured against standards based on long-term field calibration of soil tests that have established base data. These standards indicate whether the nutrient levels in the tested soil are satisfactory and whether the plant is likely to respond to fertilising. This concept includes analysis of nutrients that become toxic to plants if over-supplied.

Some soil testing organisations use analyses that are out of date and not based on rigorous scientific testing. For example, during the 1950s the standards for a healthy soil were based on the principle that healthy crop and pastures grew in healthy, well balanced soils. Soils from paddocks with healthy crops were analysed and standards were drawn up based on these results. The most famous standard derived from this method is that the calcium magnesium ratio must be between 4 and 5 (see below). However, the standard was never scientifically proven and it has since been tested and found wanting.

Feeding the soil

Feeding the soil requires annual applications of nutrients both to replace the nutrients expected to be used by the plant, and to increase the level of nutrients in the soil. Once the soil test shows that nutrient levels are at their optimum, a maintenance application equal to the amount removed by the crop is applied to prevent the crop from lowering soil nutrient reserves.

The conservation of a soil's nutrient-supplying capacity has strong appeal but two problems can arise. First, it discounts the economic aspects so important to the farmer where the soil's delivery capacity of a given nutrient may be adequate for top yields for some years to come. See the discussion on calcium and magnesium below. Second, the estimates for nutrient removal in the crop are usually calculated from average elemental concentrations and estimated or measured yields, and these can vary enormously, for example nitrogen amounts in wheat.

Calcium and magnesium deficiency

Nearly all soils in Australia contain an adequate supply of both magnesium and calcium for the crops and pastures grown in this country. Yield responses in crops and pastures to applied soluble (and thus readily available) calcium or magnesium are very rare (Bruce 1999, Aitken, Scott 1999). Some fruit and vegetable crops are affected by deficiencies of these two nutrients and are no doubt covered in specific recommendations for those crops.

Calcium

Generally, less than 40% calcium of the exchangeable cations less exchangeable aluminium is associated with calcium deficiency. Absolute deficiency of calcium is not common in Australian soils. Acid soils with low cation exchange capacity in high rainfall environments are most likely to show low calcium status. (Bruce 1999).

Where there is a marginal soil calcium deficiency (between 40 and 50% exchangeable calcium or less than 1.0 cmol(+)/kg), and growing conditions are most favourable, a calcium deficiency may occur in those parts of the plant that are furthest from the main flow of water within the plant. Examples are poor seed set in peanuts and subterranean clover, and blossom end rot in tomatoes. More severe calcium deficiency may cause death of growing points, for example November leaf in bananas. Low levels of soil calcium can also adversely affect the nodulation of subterranean clover.

Examples of very severe calcium deficiency (less than 30% exchangeable calcium or less than 0.5 cmol(+)/kg) are most likely in soils with a pH less than 4 that are sandy and low in organic matter, or where there has been excessive use of highly acidifying fertilisers. As these soils have very high levels of soluble aluminium, all but the most acid tolerant plants, such as sugar cane, are killed before the symptoms of calcium deficiency become apparent.

Magnesium

Loss of production in crops and livestock due to a magnesium deficiency in the soil is most unusual in Australia (Aitken, Scott 1999). As with calcium, the best indicator of availability of magnesium is the exchangeable magnesium expressed as a percentage of the exchangeable cations less exchangeable aluminium.

Less than 2% exchangeable soil magnesium has caused magnesium deficiency in young crops and pastures in southern NSW. However, a more than adequate level of available magnesium in the subsurface layers meant there was no effect on yield as ample magnesium came available to the plant as the roots extended into the sub-soil. In NSW, with a few notable exceptions, all soils have ample supply of magnesium in the subsoils (Brendan Scott pers.comm).

At the other end of the scale of exchangeable magnesium, greater than 30% of the cation exchange capacity can be associated with dispersive soils, particularly if the exchangeable sodium is less than 12% (Yin Chan pers.comm).

Grass tetany in cattle is sometimes attributed to low soil magnesium. In fact magnesium is required by cattle in massive amounts, particularly after calving, and cannot be stored in the animal. To vary the magnesium content in a pasture sward by 5 or 6% will not overcome a grass tetany problem arising from insufficient fodder.

Calcium magnesium ratio

There is a theory that for a soil to be healthy it will have a calcium magnesium ratio of about 4 to 5. This ratio does not refer to the cation exchange capacity of the soil. In fact there is no experimental evidence to support this theory, while on the other hand there are several experiments that show that it is not true. Research clearly indicates that the exchangeable cations must be known to compute the basic cation saturation percentage (Haby et al 1993).

Research at Wagga Wagga Agricultural Institute has shown that the calcium magnesium ratio is a poor indicator of magnesium and calcium fertility problems. This research has shown there is no response in the field to increasing the ratio up to 20:1 for number of crops and pastures (Scott, Conyers 1995). In part this is explained by an ample supply of magnesium in the subsoil that balances any deficiency of magnesium or excess of calcium in the topsoil.

Predicting the response to liming

Research in the 1970s and 1980s has clearly shown that knowledge of pH and exchangeable aluminium (Al_{ex}) levels is required to confidently predict a response to lime in crops and pastures. Until this research, exchangeable cations were determined using reagents buffered to either pH 7.0 or 8.4. Liming rates were based on a need for calcium. This is now regarded as outdated technology. For a useful lime recommendation you also need to know whether your crops or pastures are sensitive to soil acidity and the pH below the soil surface layer.

Nitrogen, phosphorus, potassium and sulfur

Traditionally, soil tests have been used to determine how much nitrogen, phosphorus, potassium and sulfur are needed to fertilise plants for optimum crop and pasture production. However, analysis of the top 10 cm of soil is only one aspect to consider when deciding on fertiliser. For example, the greatest response to phosphorus, sulfur and potassium fertiliser applied to a pasture occurs in the legume component. Where there is no legume there is little point in correcting a deficiency in any of these elements. Similarly, it is essential to know the disease status of a paddock when calculating the rate of nitrogen fertiliser for a wheat crop, because disease will reduce the plants' response to nitrogen.

The top 10 cm of soil is an arbitrary depth agreed to by most Australian organisations involved in correlating soil tests and plant response or conducting soil tests. Without this agreement comparisons between research and soil testing cannot be made.

Phosphorus

Unfortunately, scientists have never been able to agree on which test is the best to predict response to phosphorus. There are two methods commonly used in NSW. These are:

- Bray 1 P: 1 part soil to 7 parts dilute HCI/NH_4F. Shake one minute and filter.
- Colwell P: 1 part soil to 100 parts 0.5 $\underline{m}$ $NaHC0_3$ - pH 8.5. Shake 16 hours and filter.

Generally the Bray test is regarded as more reliable in acid soils while the Colwell test is best suited to neutral to alkaline soils. However, there is little to suggest that either test is better than the other. The two tests use differing extractants, shaking times and soil solution ratios to extract phosphorus from a range of sites in the soil and in differing amounts. The Colwell test when compared with Bray over a range of soils may vary tenfold depending on soil properties. This variation is largely due to phosphorus sorption, a simple laboratory test that measures how much phosphorus a soil will remove from solution. The greater the amount removed, the higher the phosphorus sorption and the higher the result by the Colwell test when compared with the Bray test. Unfortunately no commercial soil testing laboratories offer a phosphorus sorption test on a regular basis. In the absence of a measure of phosphorus sorption it is essential to establish knowledge of the local soils, and local experience of the response to phosphorus, before recommending phosphorus fertiliser.

Potassium

Potassium is more mobile in the soil than phosphorus and over time can be leached down the profile. It also can be released into the soil solution from points of storage or from the mineral at a greater rate than phosphorus. Therefore a snapshot of how much potassium is available at any one time as measured with a soil test will not indicate how much may be available in three, six or twelve months time.

There are two tests available at present in NSW. The first is a measure of potassium present in the Colwell phosphorus extract, and the second the exchangeable potassium. There are other tests such as NEAP (non-exchangeable available potassium) that have not been adopted by the soil testing laboratories. Gourley (1999) suggests that it is time that we stopped arguing about the soil test and got on with correcting the obviously potassium deficient soil in Australia.

Nitrogen

The current soil test for crop nitrogen is determined from soil samples up to one metre in depth, as this is the rooting depth of most crops, and nitrogen can easily be leached to that depth. The interpretation of the soil test requires an estimate of how much more nitrogen will be mineralised between the time of the test and when the crop demand stops. An estimate of the proportion of the available nitrogen that will be available to the plants is also required. This is an area of science that is changing rapidly and best source of information is the soil testing laboratories currently offering the test.

Sulfur

Soil analysis has historically been of little value to predict a likely response to added sulfur. Various techniques and extractants have been used, but all have been unsuccessful because they remove only the sulfate portion of the total sulfur, and do not take into account the valuable organic sulfur pool, from which a substantial amount of sulfur is supplied to plants. Since 1992, the KCl-40 sulfur test, a soil test that removes sulfur from sources similar to the growing plant, has been available. This test copies the plant by measuring both readily available inorganic sulfur and the proportion of the organic pool that rapidly mineralises into organic, plant available form (Duncan 1995). Developed at the University of New England, this test has been a significant and valuable breakthrough in assessing soil sulfur levels and predicting plant responses. Like all soil analyses, it requires careful interpretation to be effective. Various local factors need to be taken into account, otherwise it could result in inaccurate fertiliser recommendations

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Trace elements

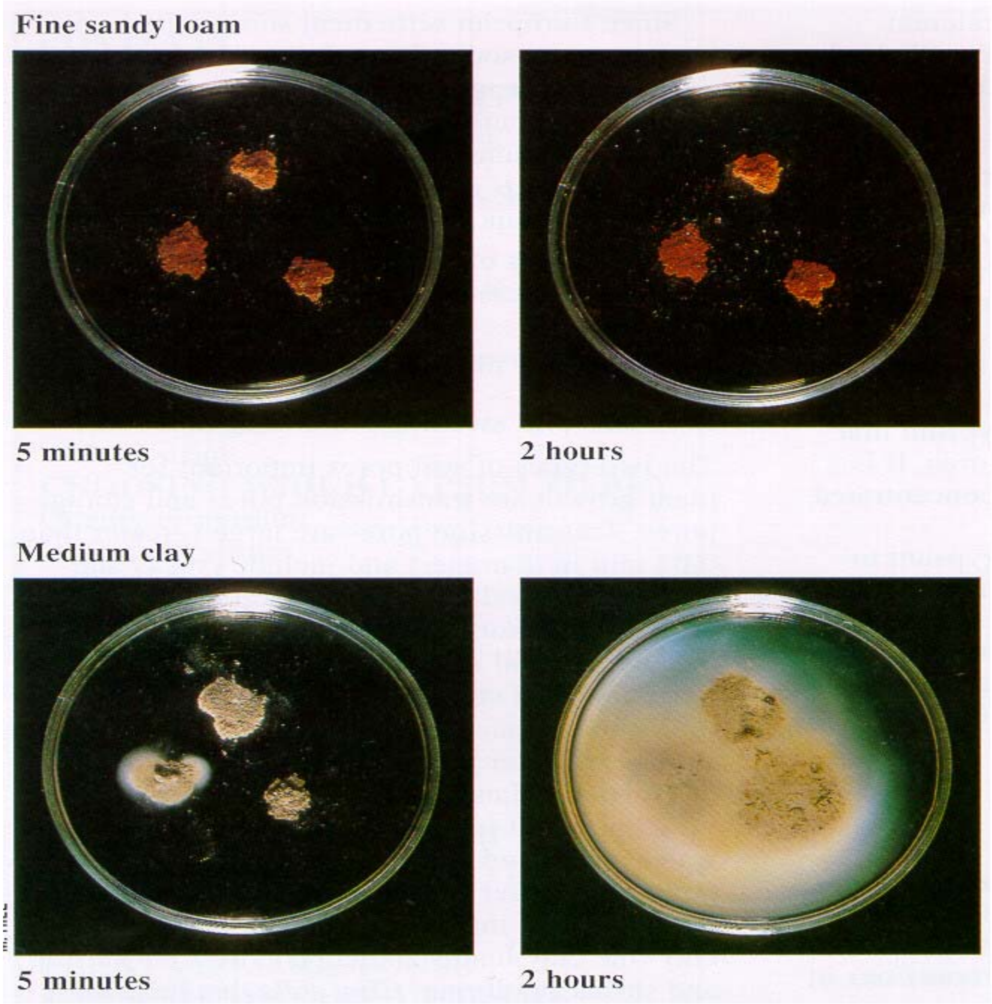
Trace elements occur in very small amounts. For example, a molybdenum deficiency can be corrected with less than 100g/ha of molybdenum applied as molybdenum trioxide or sodium molybdate every four to five years. This represents 100g mixed into 1600 tonne of soil (the weight of one hectare of soil to 10 cm deep). In addition, analysing a 10g sample drawn from 1600 tonnes to determine the availability of a trace element is not likely to be very reliable. Generally, it is better to use the relationship between soil pH and availability of a trace element to predict a response.

Testing physical characteristics

Structure and texture tests are the most used physical attribute tests. Some aspects of soil structure can be determined by placing a crumb of the soil in a dish of distilled water and leaving it for two hours as shown in Figure 1. If the soil disperses then it is likely that the soil structure can be improved with an application of gypsum of two to 10 tonne per hectare. If the slakes or collapses, the structure is weak due to poor organic matter bonding. The many aspects of improving soil structure with gypsum and lime are discussed in Agfact AC 10 and elsewhere in this workshop.

The other main physical soil test is assessment of texture. Apart from giving a better understanding of the soil, texture can be used in lieu of cation exchange capacity as a guide to lime requirement.

Figure 1. Structural breakdown of aggregates after two hours. The crumbs of fine sandy loam have not dispersed but the one on the left of fine sandy loam has 'slaked'. The crumbs of medium clay have all dispersed, and slaked.



Conclusion

In my experience, a healthy soil is characterised by a fine texture that maintains good internal drainage. To keep the soil healthy we need to monitor its chemistry and apply fertiliser, lime and gypsum based on vigorous and robust scientific research.

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From mining waste to artificial soil

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Revegetation of industrial sites can require large amounts of topsoil which is often very costly. When Broken Hill Pty Ltd (BHP) steelworks in Wollongong NSW undertook a major revegetation program on its 800 ha site, it created an artificial topsoil from industry by-products to overcome the cost problem. The soilmix comprised coal washery refuse, blast furnace slag and sewage sludge in a 2:1:1 ratio. Coal washery refuse is the by-product of washing coal (shale and clays) and the alkaline (pH 9.4) black waste is pressed into 2-20 mm sized fragments. Blast furnace slag is the by-product of the iron-making process at very high temperatures, has a pH of 9.2 and is granulated to 0.2-2mm size (see Thompson, Makin 1990). The sludge (biosolids) is anaerobically digested after sedimentation, and dewatered at several sewerage treatment plants in the area. This component provides organic nitrogen (5%), phosphorus (1%) and carbon, plus a suite of microorganisms.

The blended BHP soilmix is a black gravelly sand which is relatively homogeneous and initially alkaline. It has a particle distribution of 53% >2mm, 36% sand, 8% silt and 3% clay. It was spread 15cm deep over coal wash mounds in discrete 'gardens' (75-5000 m^2) on the steelworks site and vegetated with tubestock native trees, shrubs and groundcover species (Thompson, Makin 1990). A large suite of plant species was initially chosen for tolerance to alkalinity and salt, and species that grew well in the soilmix were subsequently used more frequently. Coarse woodchip mulch was usually spread on top of the soilmix and gardens were watered for a year. After problems with weed growth, a weedmat of tightly woven plastic material was pinned over the soilmix before mulch was laid in most gardens from about 1991.

Characterisation of man-made soil development has mostly involved physical and chemical changes such as mine spoil particle weathering, horizon formation and nitrogen accumulation. The importance of biological activity however is that plant roots, bacteria, earthworms etc may determine the rate of change of the physical and chemical properties (Anderson 1988). Studies focussing on biological activity have shown increased microorganism activity (Cundell 1977, Gildon, Rimmer 1993) and enzyme activity (Stroo, Jencks 1982) with mine soil age. Diversity and abundance of soil invertebrates such as Collembola have also increased over time on rehabilitated sites (Hutson 1980, Greenslade, Majer 1993). Many of the improvements in soil condition over time have been attributed to the accumulation of organic carbon, from either vegetation, including roots, and/or soil organisms.

The aims of this research were to determine the changes in the physical, chemical and biological characteristics of the soilmix in terms of its ability to support plant growth and potential long term sustainability. The focus was to quantify the rate and extent of soil processes occurring in the mix, including particle weathering, nutrient cycling, microbial decomposition and macroinvertebrate colonisation.

Experiments

This research studied the short-term (0-2 yrs) and longer-term (2-10 yrs) soil development in the artificial soilmix. A field trial was established where several soil plots were planted with trees or crop species and important physical, chemical and biological factors were measured intensely over approximately two years. Measurements included particle size distribution, bulk density, soil nitrogen, phosphorus and pH, and plant growth. The longer-term research included a study of a chronosequence of gardens that ranged from six months to eleven years old, and assessment of indicators of soil development and rate of soil formation. Measurements included soil particle size distribution with depth, bulk density, structure, soil carbon, nitrogen, phosphorus, pH, available nutrients, earthworm and slater density, microbial decomposition rates (calico method, Springett 1976) and mulch depth.

Field trial results

In the field trial, tree growth on the soilmix plots was exceptionally good. Average trunk diameter (and height) increased rapidly over the two years monitored: a 14-fold increase in trunk diameter for *Corymbia maculata,* an 8-fold increase for *Acacia* and two-fold increase for *Callistemon*. There were high levels of available nitrogen in the soilmix when the plots were first established. Nitrate-nitrogen content averaged 169 mg/kg and ammonium-nitrogen averaged 50 mg/k. These levels declined rapidly over the first three months (Table 1). Both were less than 15 mg/kg by six months and remained static for the next six months. Total phosphorus initially decreased then built up over time. The pH of the soil mix was initially 7.6 and decreased to slightly below 7 after three years. Bulk density was initially 1.0 g/cm^3 and remained the same after three years (Table 1). In the <2mm sized soil portion, there was a increase in the finer fractions after one year, indicating particle weathering.

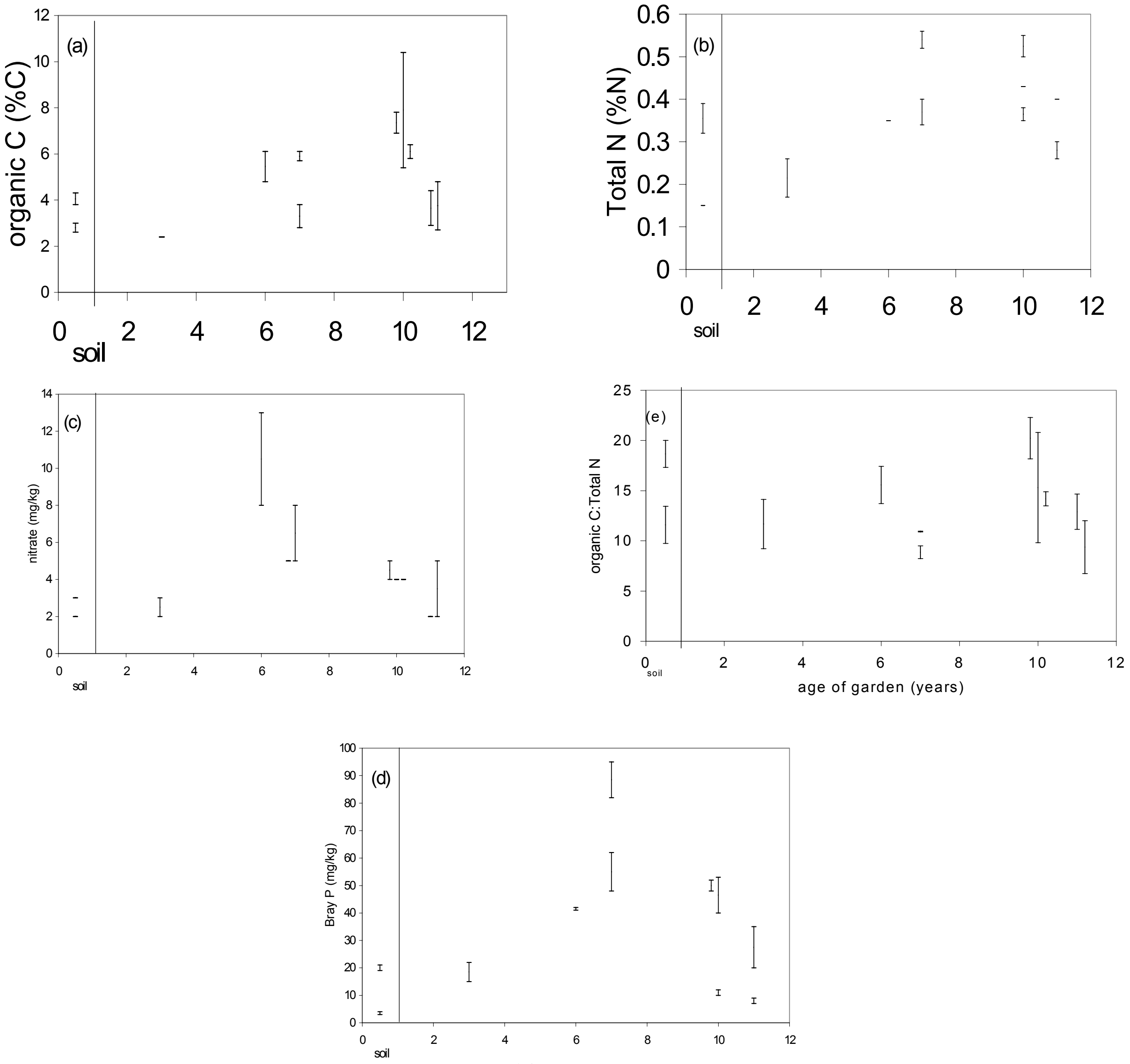
Table 1. Chemical and physical properties of the soilmix in the experimental plots (n=8) over three years (average value with standard error in brackets) from Cox & Whelan (2000).

Property	Time since plot establishment (months)					
	0	3	6	10	12	36
nitrate (mg/kg)	169 (43.8)	43.4 (4.1)	13.4 (3.3)	4.3 (1.0)	13.1 (1.3)	-
ammonium (mg/kg)	50 (13.0)	12.9 (3.5)	14.7 (1.7)	15.3 (2.0)	14.4 (8.1)	-
total P (mg/kg)	740 (115)	267 (67)	389 (61)	851 (177)	2024 (831)	-
PH	7.62(0.02)	-	-	-	7.10 (0.02)	6.85 (0.05)
bulk density g/cm^3	1.0 (0.02)	-	-	-	-	1.0 (0.03)

Chronosequence results

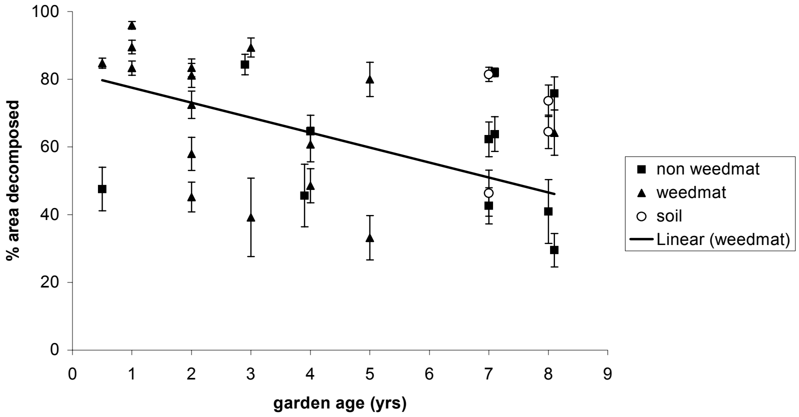
Over the three to 11 years, there was a similar trend for all nutrients measured. Organic carbon, total nitrogen, nitrate nitrogen and phosphate phosphorus were all lowest at the youngest age, higher in the middle years (6-10) and then lower in the oldest gardens (Figure 1). There were no significant relationships between age of garden and each nutrient. The youngest garden (three years) was generally in the nutrient range of the soil gardens, as were the oldest gardens (11 years). Organic carbon reached quite high values, from 2.4% at three years and a highest level of 10.4% at 10 years. Total nitrogen was high overall and averaged 0.2% at three years and 0.44% at 10 years. Average nitrate nitrogen and phosphate phosphorus increased from three to six years, then decreased. The ratio of organic carbon to total nitrogen showed no change over the three to 11 year period and remained in the range of the soil gardens (10–20), due to similar changes in carbon and nitrogen.

Figure 1. Relationship between age of gardens and chemical properties (a-e). Data are range of two (composite) samples. Horizontal lines indicate identical value. From Cox &Whelan (2000)



Decomposition decreased with garden age, with the highest decomposition observed in the one year old gardens (Figure 2). The gardens with weedmat contributed most to this relationship. Gardens with weedmat had a significantly higher decomposition rate than gardens without weedmat. Many holes had appeared in the fabric due to roots and invertebrate penetration, especially at the litter-soil interface. Large purple, brown, orange, white and black colour spots were seen which could be attributed to fungi. Evidence of decomposition was usually seen over the entire calico piece with the 0-3 cm fraction particularly decomposed, but also seen to depths of 20cm. By years 7/8, the % area decomposed in the soilmix was significantly less than the native soil gardens.

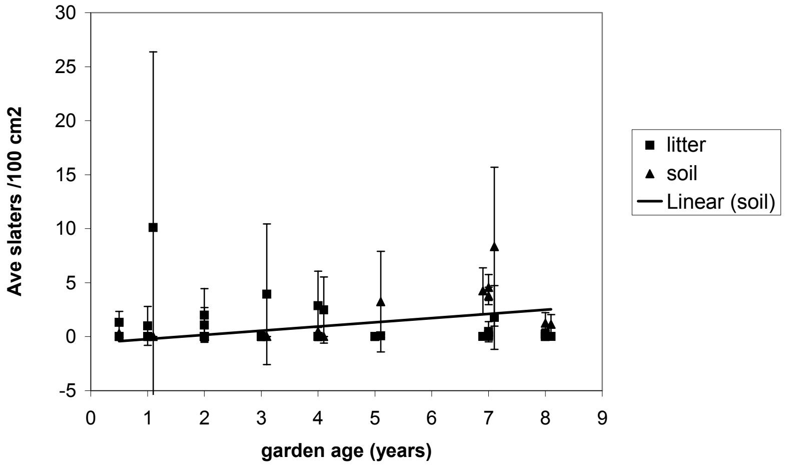
Figure 2. Average area (± standard error) of % calico decomposed after three months in soil mix and native soil gardens (six months to eight years old) from Cox & Whelan (1998).



Soil pH decreased significantly with garden age. The youngest soilmix garden had a pH of 8.56 and the oldest a pH of 7.28. Native soil gardens had lower pH levels with a range of 6.32 - 7.33. Slater density increased with garden age, regardless of weedmat (Figure 3). Average slater density ranged from 0-8.3 per 100 cm^2 for soil and 0-10.1 for litter, with the highest density of 34 slaters recorded. There were more slaters in the litter with increasing litter depth. Very few or no slaters were recorded in the soil from the younger gardens. Most of the slaters were found at the soil-litter interface, commonly buried just below the soil surface when the litter was pulled back.

There was no relationship between earthworm density and garden age, although the average numbers were low and earthworm distribution was quite patchy. Earthworm density was generally highest in the soil for the older gardens and in the litter for the younger gardens. No slaters or earthworms were found in the 'soil only' fraction from gardens with weedmat. These organisms were found, often in abundance, in the litter layer above the weedmat. Other taxa of invertebrates observed in the soilmix and litter included ants, springtails, amphipods, nematodes, mites, spiders and beetle larvae. There were more slaters found in the soilmix than in the native soil.

Figure 3. Average slater density (± standard error) in the soil mix gardens from 6 months to 8 years, in soil and litter. From Cox & Whelan (1998).



Discussion

The field trial showed that the rate of change in the soil environment was very rapid. The high nutrient content at the beginning of the experiment contributed and was indicative of sludged soil. The initial flush of nitrate-nitrogen would have resulted from organic nitrogen transformations in the soil via microbial action (Wild 1988). The subsequent decrease over time was also found by Joshua and Salt (1996) when sludge was applied onto agricultural land. This available source of nitrogen and phosphorus would have been used by the trial plants in their expansive growth. Both crop and native species produced considerable biomass over the two years. It is well known that biosolids application increases plant growth (Topper, Sabey 1986, Wong, Ho 1994). This growth also translates to extensive root production, which in turn would contribute to improving the soil structure of this homogeneous material. The transformation of the organic matter by microorganisms into organic acids and the leaching of soluble molecules helped decrease the alkalinity of the soil mix. The actions of the chemical, physical and biological forces interacted to produce quite rapid soil development, and showed that the soilmix had undergone natural soil processes that may eventually lead to self-sustainability.

The chronosequence study gave an opportunity to quantify the soil development over 11 years. The increase in organic carbon and total nitrogen in the soil was a positive indicator of litter and mulch accumulation as the sludge nutrients were used. This showed that the sludge carbon and nitrogen were being utilised by plants and animals, but these nutrients were being incorporated back into the soil system in a continuous cycle. This is the initial establishment of the nutrient cycling process, which is critical in maintaining a self-sustainable ecosystem. Available nitrogen and phosphorus were also at high levels, above that of gardens with native soil. The generally high carbon nitrogen ratio of the gardens indicated the presence of much partially decomposed material (Jenkinson 1988) but was stable over the 11-year period. As the carbon nitrogen ratio is an indication of rate of organic matter decomposition, it is a useful measure of long-term viability of restoration and rehabilitation.

The importance of biological activity

The very active decomposer microorganisms contributed enormously to the rapid soil development in the soil mix. The organisms were responsible for breaking down organic matter to available nutrients for plants and animals in the artificially created ecosystem. The plentiful nutrients allowed rapid tree, shrub and groundcover growth, which themselves contributed to soil development through root exudases and litterfall back to the soil surface. The larger macroinvertebrates (such as slaters, earthworms and collembola) were responsible for breaking down this litter into very small fractions and incorporating it throughout the soil profile, where the fungi and bacteria then acted upon small particles. Dead and decaying animals provided food for other organisms and plants, and the cycling of nutrients was established. The oldest gardens showed the highest number of slaters, high % organic carbon, stable carbon nitrogen ratio and had established identifiable horizons (data not shown) along with a diverse suite of organisms. The soilmix environment shows promise as an alternative to topsoil, where this precious resource is unavailable.

Conclusions

The role of the plants and animals in the soil is vital and should not be underestimated. The chemical and physical environment is shaped by the activity of microbes, invertebrates and plant roots. As the soil mix contained a suite of microorganisms and also importantly, high amounts of organic nutrients (carbon, nitrogen and phosphorus) at the beginning (from the biosolids), the conditions were suitable for a fertile, active soil. The available form of nitrogen and phosphorus to plants allowed them grow rapidly, sending roots throughout the soil to stabilise and add to structure. The sludge organic matter, mulch, then litterfall provided a continuous source of organic carbon for the microbes to use as substrate and therefore were present to transform organic material into available forms. The slaters and earthworms shredded and incorporated litter material into the soil where it became available to the microbes. These activities increased soil structure by the formation of soil aggregates and along with natural weathering processes, created distinct horizons as displayed by native soil. The complete hierarchy of soil organisms, from microbes, protozoa, collembola and mites to earthworms is essential for soil functioning, whether the soil is used for restoration, mine site rehabilitation, agriculture or conservation. Incorporation of biological factors with chemical and physical factors is essential in assessing soil function and soil health.

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Organic cereal growing and soil health: a discussion paper

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On broadacre organic farms in the pasture-cropping area of NSW, cereal cropping tends to occur less frequently and grain yields are commonly lower than on conventional farms. For example, on a long-term organic farm at Ardlethan in western NSW, average practice has been two cereal crops following six pasture years, compared with three crops following three pasture years on a neighbouring conventional farm (Derrick 1996). On some organic pasture-crop farms, pasture length may be as long as nine years preceding one or two crop years. On the Ardlethan organic farm, and an organic farm at Yenda in southern NSW, crop yields averaged 52% of neighbouring conventional crop yields (Derrick 1996). In Western Australia, one study (Deria et al 1996) showed crop yields averaged 85% of those on neighbouring conventional farms.

Crop yield reduction and less frequent cropping can contribute substantially to lower gross margins on organic farms compared with conventional farms (Penfold et al 1995). Presumably gross margins on organic farms will be even lower in times of low livestock prices. The constraint of building adequate 'organic' soil fertility through a relatively long pasture phase inevitably reduces organic farmers' flexibility to switch between livestock and cropping enterprises in response to changes in the relative profitability of the enterprises. There is a need to increase average crop yields and cropping frequency on organic broadacre farms.

In our three year project funded by RIRDC we are

- obtaining recent and comprehensive soil nutritional data from organic farms in central and southern NSW
- examining processes by which the quality and productivity of pastures on organic farms can be improved to increase cropping frequency and/or yield.

We hypothesise that improvements to soil nutrient status (particularly phosphorus and sulfur availability and pH) and pasture management are essential.

Experimental program

Soil survey

A survey of organic soils on broad-acre cropping farms has begun in south-western NSW to characterise their nutrient 'health'. The soils (0-10 cm) are being characterised for pH ($CaCl_2$), total carbon, nitrogen and sulfur (LECO CN&S analyser), total phosphorus, available phosphorus (Olsen), organic phosphorus, available sulfur, organic sulfur and microbial biomass (substrate induced respiration).

Some initial survey results are given in Table 1. Although there have been few comprehensive studies of soil nutrient trends on Australian organic broadacre farms, the data suggest trends to soil deficiencies in available phosphorus and, not invariably, to deficiency in sulfate. Interestingly, at the Ardlethan organic farm cited above, soil total nitrogen was not dissimilar to that on the neighbouring conventional farm, yet average crop nitrogen concentration was lower on the organic farm (Derrick 1996). Therefore, the reasonable soil nitrogen concentrations on the organic farms as shown in Table 1 may not be as indicative of the nitrogen supply to crops as might be projected for a conventional farming system.

The survey has just been initiated and our conclusions are necessarily tentative. Notwithstanding, Table 1 shows that available phosphorus may be commonly suboptimal and, depending on the organic farm or paddock, soil pH and sulfate also. Compared with conventional farm soils it is not yet apparent that organic soils have higher organic carbon content nor higher organic phosphorus. The ratio of microbial carbon to total carbon (MC / TC) on the one organic farm (Henty, Table 1) assayed so far is perhaps lower (1.9%) than desirable.

Table 1. Soil characteristics. 1P = conventional permanent pasture (Wagga), 1C = conventional pasture -crop rotation (Wagga). Other sites are organic farms.

Soil characteristic	1P	1C	Henty	Illabo	Uranquinty	Ardlethan
1. pH	4.4	4.6	5.1	4.3-5.1	4.3-4.5	5.2-6.1
2. Total carbon (%)	1.9	1.8	2.0	na	na	1.4
3. Total nitrogen(%)	0.22	0.21	0.20	na	na	0.18
4. Available phosphorus (mgP/kg)	10	16	5	8-16	3 - 6	5 – 9
5. Organic phosphorus (mgP/kg)	161	164	159	na	na	125
6. Available sulfur mgS/kg)	na	na	Na	< 3.4	< 3.4	5 - 17
7. Microbial biomass carbon ug/g	296	169	428	na	na	na
8. Ratio of microbial carbon to total carbon	0.016	0.009	0.019	na	na	na

1.$CaCl_2$ (1:5,0.01M). 2 & 3. Total C and N (LECO C&N Analyser). 4. Olsen phosphorus.

Suboptimal soil levels of phosphorus, sulfur and pH may indicate insufficient inputs of nutrient and lime or, in the case of available phosphorus, to the use of relatively insoluble rock phosphate. In organic farming systems, high pasture legume productivity is fundamental to supplying nitrogen to succeeding crops, because mineral nitrogen fertiliser cannot be used. We hypothesise that the suboptimal phosphorus, sulfur and pH (for acid sensitive species) on organic farms will inevitably constrain both the rate of soil nitrogen accumulation during the pasture phase and perhaps the ultimate soil nitrogen level. Consequently, the key to increasing crop yield and cropping frequency is to sustain an improvement in the productivity and abundance of legumes in organic pastures, pivotal to which is to increase soil available phosphorus, and available sulfur where required.

Field experiments

Increasing the soil sulfate supply is readily achievable with gypsum. It is more difficult to increase the availability of phosphorus, and several factors are important: fertiliser composition, soil pH, soil moisture, and the concentration of phosphate and calcium in soil solution. Dissolution of the rock phosphate is facilitated when soil solution phosphate and calcium concentrations are low. This is achieved by removal of phosphate and calcium through plant uptake, preferably. Other ways that these concentrations are reduced is through leaching of the ions or through their fixation to the mineral and organic components of the soil (Bolan et al 1990). Field trials to investigate these factors have been established at two sites that represent scenarios that may occur widely:

- organic soils of low pH (<4.8), low phosphorus and low sulfur
- organic soils of higher pH (> 5.0), low phosphorus, variable sulfate.

At both sites the importance of elevating phosphorus inputs using newer, organic-approved phosphorus fertilisers, and elevating soil sulfate using gypsum, will be tested. In addition, the Illabo site will focus on the effect of modifying pH, either a decrease or increase, on phosphorus cycling. A decrease in pH will be effected using elemental sulfur, and this soil treatment will necessitate establishing an acid tolerant pasture. An increase in pH will be effected with lime, and will be associated with clover pasture. The Ardlethan site will focus on the effect on phosphorus cycling of farming practices that conserve soil moisture and/or increase soil inputs of carbon. The major treatments for each site are summarised below.

Illabo site

pH = 4.5, phosphorus = 7.6 mg/kg, sulfur < 3.5 mg/kg

Treatment A

- acid tolerant pasture (yellow serradella / yellow lupin)
- reactive phosphate rock fines (3% available phosphorus); nil, 500 kg/ha
- Durasulph (6% phosphorus) – granular; nil, 500 kg/ha
- each of the above +, - elemental sulfur 500 kg / ha

Treatment B

- lime responsive pasture (subterranean clover)
- reactive phosphate rock fines (3% available phosphorus); nil, 500 kg/ha
- Durasulph (6% phosphorus) – granular; nil, 500 kg/ha
- each of the above +, - lime; 2000 kg / ha

Treatment C

- wheat undersown with subterranean clover (farm control)
- subset of treatments; +,- gypsum

Ardlethan site

pH = 5.6, phosphorus = 6.5 mg/kg, sulfur = 11 mg/kg (5-17)

Treatment A

F=fallow LGr=legume grazed Lco=legume forage conservation
LGm=legume green manure

F	LGr	LGr
F	LCo	LCo
F	LGm	LGm
F	F	F

Treatment B

Reactive phosphate rock fines (3% phosphorus) with elemental sulfur 500 / 500 kg/ha, nil (across treatments A & C)

Treatment C

US LGr LGr
(Wheat under-sown with subterranean clover)

The impact of the various treatments on annual pasture composition, productivity and nutrient uptake, soil available nutrients, organic nutrient concentrations, and on wheat production in the fourth year, will be measured.

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Natural growing systems: horticulture and soil health

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This paper considers some threats and opportunities in north coast perennial horticulture in relation to soil health. One context in which these issues could be addressed is holistic natural growing systems approach, in which soil is considered a dynamic, living resource whose condition is vital to the production system.

Soil health is obviously a complex area and consequently systems approaches, rather than compartmentalised, issue-driven approaches, are essential. These systems need to be incorporated in production systems to ensure adoption, hence the need for a natural growing system approach.

Natural growing systems

Natural growing systems place a high priority on issues such as soil health rather than, for example, the narrower view of soil quality. Some of the proposed features of natural growing systems are that they have a strong emphasis on minimising inputs and disruptions, and protecting and replenishing natural capital, especially the soil. They include organic growing systems and more enlightened sections of conventional production systems where best practice systems take account of sustainability issues.

Natural growing systems need to encompass environmentally sound technologies, cleaner safer techniques, and efficient use of raw materials. Some of the strategies that are obvious to a natural growing systems are biomimicry (imitating nature in areas such as biocontrol and nutrient cycling) and repletion of natural capital, while less obvious but essential features are high level product value and resource productivity. The latter strategies underpin the need for economically viable systems that can allow further investment in sustainability, and the need to acknowledge demand for production from a limited resource base. It is necessary to meet national and worldwide demand for food without a massive increase in land recruited for agricultural production.

Soil health issues

Some of the first order issues facing north coast horticulture summarised by Moody (1995) are the need to

- maintain and enhance organic matter levels
- prevent or correct surface and subsoil acidification
- minimise erosion
- maintain fertility by replacing nutrients removed by harvest, leaching, and fixation.

Although Moody was considering krasnozem soils particularly, this list encapsulates issues facing north coast horticulture generally. We can add to the list the need to minimise the harmful effects of soil contamination by pesticides.

The use of cover crops

Cover crops can help address two major issues for horticulture on the north coast. One is soil protection from erosion, which is critical because of our combination of slopes and high rainfall that make wholesale bare soil unacceptable. There is also the opportunity to alleviate some of the effects of long term monoculture. For example interrow cover crops can provide additional nutrient sources to the crop (eg legumes contribute to soil nitrogen), increase soil organic matter, and improve orchard biodiversity (both above and below ground). However care is needed to avoid species that encourage pests or pathogens of the crop.

An example of the need for cover crops is the macadamia industry. In young plantations reasonable cover can be maintained, but as the density of the canopy increases many species of plants die out due to shading, so shade-tolerant cover crops are needed. The industry's requirement for a flat, dense surface to enable nuts to be harvested from the ground means cover crops must be low growing, dense and amenable to close mowing. Industry-funded research has successfully identified a number of suitable cover crop species, and it now remains to address adoption issues. While the soil erosion aspect of cover crops is evident, the case for adoption could be enhanced if data on more systemic soil health benefits were available.

There are similar opportunities in banana plantations to develop cover crop management techniques as an alternative to bare-earth weed spraying. While some soil protection is afforded by the large amounts of crop residue provided by bananas, further protection by cover crops on slopes would be desirable. Additionally it is tempting to think that cover crops could address some of the soil health effects of long term monoculture (up to 60 years or more).

New technologies to measure soil health through microbial activity assessments will help to realise these potential benefits. However there is no room for simplistically recommending cover crops as they can be over-competitive, leading to yield losses (Johns 1991) which can be as high as 25% in organic crops (O'Donnell pers.comm). Strategies for herbicide use to manage cover crops by strip spraying to limit competition with banana plants, are needed to replace the older approach of removing all plantation floor weeds with routine broad area glyphosate treatments.

Best practice fertiliser technologies

Maintaining soil fertility is essential to ensuring productivity and product quality. Fertiliser practice has important implications for onfarm soil health and off-farm impacts. Growers are making large-scale gains by using better basic data, application methods and management technologies. Management practices like fertilisation and irrigation address the short-term needs of the crop, but the long-term survival of the production system relies on maintenance of soil health, obviously a more complex matter. Nevertheless, underlying fertiliser programs must be appropriate for more comprehensive soil health strategies to succeed.

Fertiliser application

It is important to treat existing fertiliser recommendations with care. Moody and Aitken (1996) point out that many traditional fertiliser recommendations are based on traditional nitrogen, phosphorus and potassium field trials which are site specific and often ignore other elements such as calcium. The relatively low costs of fertilisers in horticultural systems (about 10% of costs for many tree crops) has also provided growers with little incentive to examine fertiliser use closely.

An alternative approach to fertiliser management is to estimate application rates based on nutrient removal through harvest, fixation and leaching. Estimates using this approach indicate that application rates have been excessive in crops such as capsicum, tomato, coffee, bananas, mangoes and macadamias (Moody, Aitken 1996) and in passionfruit and avocados (Huett, Dirou 2000). Misunderstanding of fertiliser needs led to some spectacular cases of fertiliser build up in bananas (Johns, Vimpany 1997) which have been corrected by adoption of more appropriate application rates combined with fertiliser monitoring and improved application strategies.

Adverse effects of fertiliser application can be minimised easily or avoided. Applying annual fertiliser needs in one or two lump applications is a practice that leads to inefficient uptake and surface runoff. Applying smaller amounts more frequently, at appropriate times in the plant growth cycle, has reduced many adverse effects and inefficiencies as evidenced in banana plantations. Fertigation, the application of fertiliser in irrigation water, represents the ultimate in accurate and timely application of fertilisers to horticultural crops and is increasingly used in best practice systems. Soil moisture monitoring systems such as tensiometers and Enviroscan®, help growers minimise water use, costs and off-farm movement. The adoption of these techniques is increasing, probably driven by economic considerations, but certainly producing desirable environmental protection outcomes at the same time.

Types of fertiliser

An important factor in soil health is the use of appropriate forms of fertiliser. A simple example is provided by Moody (1995) where using ammonium nitrate rather than urea as a nitrogen source reduces the rate of acidification by 75% under the same rates of leaching.

Monitoring fertiliser use

Techniques for moitoring and fine tuning fertiliser applications are relatively well developed. Integration of plant (and or sap) analysis and soil analysis provides essential information. The plant tissue analysis assesses the nutrient status of the trees while soil analysis allows refinement of application rates and checks for side effects such as soil acidification. As an example of a well tuned system for tree crops, avocado nutrition programs often start with a soil and leaf analysis to indicate the required application rates. This can be supplemented by three sap analyses per year to more closely monitor the achieved nutrient status of the plant (G.Anderson pers.comm). The issues raised over soil health indicate more dimensions are needed in soil and tissue analysis, particularly in terms of meaningful indicators of soil organic carbon, organic matter and microbial activity. The response of effective horticultural industries in adopting refined fertiliser programs driven by the best available technology suggests that the main inhibitors to greater attention to soil health are lack of information, reliable indicators and appropriate technologies rather than an indifference to the fundamental issues.

Minimising pesticide usage

Pesticide use exemplifies the need for a holistic approach to soil health. Several pesticides affect the soil, applied directly or indirectly to the soil, intentionally or inadvertently. Nematicides are directly applied pesticides, while herbicides and drift from foliar-applied insecticides and fungicides represent indirect applications. Clearly there are many different pesticides, from a wide range of chemical groups, and there is an important need to examine how each compound degrades in the soil and affects various soil organisms. The dynamics of the effects are also important in developing rational schemes to use these compounds.

For example understanding the dynamics of copper accumulation is important as well as knowing it can pose a threat to soil health in general. Retaining an early season application of copper in the avocado management program is important for the prevention of bacterial blotch, so that removing copper entirely could lead to this minor disease emerging as a major problem. Copper treatment could also have a valuable role in rotating fungicide groups to prevent resistance arising to newer alternative fungicides. In macadamia plantations, the limited use of copper sprays to achieve some residual control of husk spot is likely to greatly reduce the total use of fungicides in this program, and so assist in avoiding selection of resistance. Consequently it is of paramount importance to understand the rates at which copper accumulates and disappears from the system, in order to retain access to minimal but important treatments, if they can be combined with retention of soil health.

Another critical area of pesticide impact is the effect of herbicides. For example, we do not know whether the major effects of a herbicide such as glyphosate stem from toxicity to soil microorganisms or from wholesale depletion of plant material affected by the treatment. If the latter is the case there is presumably room for very limited use of herbicides in confined areas as opposed to broad area spraying, without major ill effects on soil health. Strategies that minimise herbicide usage rather than prohibiting them may ultimately yield better soil health outcomes. Horticultural growers and researchers need to be provided with specific and convincing data to demonstrate adverse effects of pesticides, so that better alternatives can be identified and adopted. Simplistic prohibitions may well be an impediment to better practices. In the absence of specific information on the effects of pesticides on soil health, management procedures that seek to minimise the use of the pesticides in question would appear to be advisable.

An example where the best practice approach has achieved much in this direction is the banana industry. Previous treatments that affected soil health included the application of persistent insecticides to the soil around the base of all plants (after clearing the leaf mulch from the base of the plant) to treat weevil pests, and often routine applications of nematicides to treat parasitic nematodes. Best practice growers have now reduced insecticide usage for weevils by adopting injection of old residual corms which uses 90% less insecticide that is contained within the corm without the need for a bare earth zone around the plant. Better awareness of the management of nematode pests and techniques to monitor their impact has seen many growers move away from routine treatment.

Some major challenges

A major challenge in horticulture is to provide a better understanding of the critical elements of and major threats to soil health, so that limited research resources can be directed to critical areas.

The fastest way to remove inappropriate technologies is to highlight the problem of the inappropriate technologies and provide alternatives.

We need universal indicators of soil health and, more broadly, sustainability, with well-defined threshold levels to back them up. Possibly the biggest issue at present is the lack of suitable indicators. These indicators need to

- be reasonably universal
- satisfy production aims as well as environmental concerns
- account for physical, chemical and biological factors,
- be easy to use under field conditions
- be supported by threshold values for the key indicators.

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Soil extension tools and methodologies

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Ask any land manager how important their soil is and they will invariably reply 'very' or 'without it I wouldn't be here'. Why then is it so difficult to get landholders to participate in soils information days, workshops and field days? Why do people see soils as boring? Soils have a considerable image problem to overcome both outside agriculture and within it. Land managers want to know why things happen and what they can do about it, but this approach has been lacking in soil science, and when information becomes available it is often daunting in its complexity. For far too long we ignored the practical applications of soil classification and testing, and made the language of soil science impenetrable to non-scientists.

NSW Agriculture has worked with landholders over the past decade to develop user-friendly soils information. Soil scientists and soils advisory officers have learned that it is not the soil classification that is important to landholders, but rather what this means for fertility, drainage and management, so have developed information packages accordingly. This process involves two way communication, with landholders and scientists listening to each other. Yet we still have much work to do if we are to encourage the community to become passionate about the soils they stand on.

SOILpak

NSW Agriculture has a series of SOILpak soil management manuals designed to help farmers assess and monitor the health of their soils, and manage the resource within its capabilities. The SOILpaks cover the state's main cropping industries, as these have the most impact on soil health. There are SOILpaks for cotton growers, vegetable growers, southern irrigators, southern dryland farmers, dryland farmers on the red soil of central western NSW, and dryland farmers in the northern wheat belt.

More recently, a SOILpak training package has been developed. The competency-based training course is problem-focused, and currently offers several modules on field work, sodicity, acidity, salinity and hardsetting soils. A two day training workshop covers four modules. The first day includes a general introduction to soils with considerable time in the field at soil pits and work on one of the modules. Farmers learn practical tests/observations they can carry out to assess their soil and the impact of different management techniques. The second day of the workshop is held several days later and includes two more modules appropriate to the group and location. Participants must undertake 'homework' to achieve their accreditation.

Acid sulfate soils: ASS keys to success

The booklet *ASS keys to success* is a direct response to a farmer request for information on how to identify and test for acid sulfate soils. Designed as an on-farm manual, the booklet was written in consultation with farmers from all agricultural industries affected by these soils on the NSW north coast. Throughout its development, continual changes were made in response to comments from farmers and technical experts so that so that the tests described in the booklet are easy to understand and carry out. The booklet takes farmers through the process of assessing an area for ASS risk, with step by step methods for field sampling soil. Topography, water indicators and soil indicators are all used to build up a picture of ASS in the landscape as well as onfarm. The booklet includes case studies and a reference list for further information so that users can take the next step in trialing a management option or looking for more information/resources.

Anecdotal information indicates that the booklet is successful in providing practical information based on the needs of farmers who suspect they have ASS on their property. The publication has proved a useful tool for ASS officers and landcare groups and there has even been interest from local councils and Telstra.

Soil monoliths

Soil monoliths are preserved soil profiles, a convenient and portable method of showing people what is below the soil surface. Depending on the audience, the monoliths provide general information, soil management options, soil classification information, and three dimensional illustrations of common soil degradation problems.

There are currently four sets of monoliths available. The largest and most comprehensive set covers most of the soil types on the north coast. Other sets include soils from the Sydney Basin fringe, and from CB Alexander College, Tocal, both of which have been made to illustrate soil management problems and options, and a set from the central/southern tablelands. Extension agents have found these to be excellent tools to encourage the community's interest in soils and provide useful information. The creator of the monoliths, NSW Agriculture soil scientist Roy Lawrie, showed the value of the monoliths at Tocal where two identical looking surface soils with very different production capability, produced monoliths that revealed deep structural differences.

Soil Sense workshops

Soil Sense workshops have been run on the north coast since 1992. In that time, 21 one day workshops have been held from the Tweed to the Macleay and west to Comboyne as part of the former Farming for the Future program. The workshops aim to help landholders look beneath the soil surface using soil pits. Pits are dug in two contrasting sites to encourage participants to think about the differences and the implications for land management. Participants learn to determine soil texture, assess pH levels and 'read' the information in the walls of the pit. The workshop gives people the information and skills to carry out a few field tests on their own soils and understand what the results mean so they are able to monitor their own soils. They become more aware of how their actions influence any changes taking plain soil health. As one participant commented:'It was good to actually feel the soil to use as a comparison to our own soil…I can now carry out similar observations on my own soil with more confidence.' The Soil Sense program is backed up with a series of Soil Sense leaflets, the poster 'How to read your soil' and the ever popular Soil Sense book, now in its second edition.

Integrated approaches

NSW Agriculture's soils program has worked closely with other departmental programs to incorporate soils knowledge into farm management training so that linkages are made between soils and water, irrigation, effluent disposal and vegetation management. A good example of this is the Waterwise on the Farm training course that includes one day looking at soils. Soils sessions are often included in production-based field days for farmers.

The future

The outcome of a decade of soils extension effort is that attitudes to soils are changing. The community is beginning to demand more information on soils and the department is ideally placed to ride this enthusiasm and interest by listening to farmers and the community and provide what they ask for. As one workshop participant commented after a Soil Sense workshop at Grafton, 'there should be more workshops in relation to soils'. The next challenge is letting the community know this information is available and where to get it. It is not enough to produce high quality resources and have qualified staff to present this information. Better marketing and closer linkages with community groups will help new and existing projects reach those who need the information and will guarantee that information is valid, useful and appropriate. Directly involving the community is also a good way to gather information on people's soil information needs while researching particular issues. Encouraging land managers to do their own research on farm will ensure the flow of information is both ways, which can only benefit both the community and NSW Agriculture.